The effect of age and sex on the meat quality of impala

(*Aepyceros melampus*)

ANÉL DU PLESSIS

Thesis presented in partial fulfilment of the requirements for the degree of

MASTER OF AGRISCIENCES IN ANIMAL SCIENCES

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Supervisor: Prof LC Hoffman

Co-supervisor: Prof P Strydom

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: March 2020

SUMMARY

The aim of this study was to provide baseline data on the effect of animal age and sex on the yield, physical meat quality and chemical composition of impala (*Aepyceros melampus)* meat. The analysis took place on the following six muscles: *infraspinatus* (IS), *supraspinatus* (SS), *longissimus thoracis et lumborum* (LTL), *biceps femoris* (BF), *semimembranosus* (SM) and *semitendinosus* (ST).

A total of 32 impala were used during this study. The male animals were divided into three age categories of 18-months old, 30-months old and 42-months old with eight animals per age group. The eight female animals were all 30-months of age. The 42-month-old rams had the heaviest dead weight (58.3 ± 5.99 kg) and carcass weight (34.1 ± 4.03 kg), but no differences in dressing percentage between the ages were noted. The male animals also had heavier dead weights and carcass weights in comparison to the same aged female animals. The total offal was heavier in the 42-month-old animals as well as the red offal proportion. The muscle weight increased with age, with the 42-month-old animals having the highest muscle yield.

Age did not affect the physical meat quality of the muscles that were analysed; no differences were found between the water holding capacity, shear force as well as colour between the different age groups. Sex had an influence on some of the muscles analysed. This was mainly observed in the lightness (L* values) of the muscles with the ewes having lower L* values and thus darker meat in comparison to the rams. The difference in L* values is possibly due to the difference observed in muscle pH between the rams and ewes. The female animals had a higher pH for the majority of the muscles in comparison to the rams. Despite these slight differences, it would seem as if impala have inherently high meat quality attributes ideal for fresh meat production.

The chemical composition of the muscles analysed were unaffected by age. The moisture content ranged between 75.0 ± 0.39 - 76.7 ± 0.90 g/100 g meat, the protein content between 20.8 ± 1.03 - 22.6 ± 0.41 g/100 g, the intramuscular fat content between 1.6 ± 0.31 – 2.4 ± 1.30 g/100 g, the ash content between 1.2 ± 0.07 - 1.6 ± 1.08 g/100 g as well as the myoglobin content ranged between 8.2 ± 1.17 - 11.6 ± 2.17 mg/g. Sex also had minimal effect on the proximate composition and myoglobin content of the muscles analysed. Slight differences between the muscles were observed for some of the proximate components. These differences were due to the different anatomical location and thus the function of each muscle.

The data generated will aid producers and marketers in the accurate production, marketing, labelling and consumer education regarding impala meat production.

OPSOMMING

Die doel van hierdie studie was om data te verskaf oor die effek van ouderdom en geslag op die opbrengs, fisiese kwaliteit en chemiese samestelling van rooibok (*Aepyceros melampus)* vleis. Die volgende ses spiere was vir die analises gebruik: *infraspinatus* (IS), *supraspinatus* (SS), *longissimus thoracis et lumborum* (LTL), *biceps femoris* (BF), *semimembranosus* (SM) en *semitendinosus* (ST).

‘n Totaal van 32 diere was gebruik tydens die studie. Die manlike diere was verdeel in drie ouderdomsgroepe naamlik 18 maande, 30 maande en 42 maande. Elke ouderdomsgroep het agt diere bevat. Die agt oorblywende vroulike diere was almal 30 maande oud. Die 42 maande oue ramme het die swaarste dooie gewigte (58.3 ± 5.99 kg) en karkas gewigte (34.1 ± 4.03 kg) gehad. Daar was egter geen verskil in uitslag persentasie tussen die ouderdomme gevind nie. Die manlike diere het ook swaarder dooie- en karkas gewigte gehad as die selfde ouderdom vroulike diere. Die totale afval asook die rooi afval verhouding was die swaarste in die 42 maande oue ramme. Die gewig van die spiere het toegeneem met ouderdom. Die 42 maande oue ramme het die hoogste spier opbrengs gelewer.

Die ouderdom van die diere het nie die fisiese vleis kwaliteit van die spiere beïnvloed nie. Daar was geen verskille gevind tussen die ouderdomsgroepe vir waterhouvermoë, skuifskeurkrag en kleur nie. Geslag het ‘n uitwerking gehad op van die spiere wat geanaliseer was. Die effek van geslag was hoofsaaklik waargeneem op die ligtheid (L* waarde) van die spiere. Die ooie het laer L* waardes gehad en dus donkerder vleis as die ramme. Die verskil wat waargeneem is tussen die L* waardes van die twee geslagte kan wees as gevolg van verskille wat waargeneem was in die pH waardes tussen ramme en ooie. Die vroulike diere het hoër pH waardes gehad vir die meerderheid van die spiere wat geanaliseer was. Ten spyte van hierdie klein verskille wil dit voorkom of rooibok vleis ‘n inherente hoë kwaliteit het wat geskik is vir vars vleisproduksie.

Die ouderdom van die diere het nie die chemiese samestelling van die spiere beïnvloed nie. Die voginhoud het gewissel tussen 75.0 ± 0.39 - 76.7 ± 0.90 g/100 g vleis, die proteïeninhoud tussen 20.8 ± 1.03 - 22.6 ± 0.41 g/100 g, die intramuskulêre vetinhoud tussen 1.6 ± 0.31 – 2.4 ± 1.30 g/100 g, die as inhoud tussen 1.2 ± 0.07 - 1.6 ± 1.08 g/100 g en die mioglobien inhoud het gewissel tussen 8.2 ± 1.17 - 11.6 ± 2.17 mg/g. Die geslag van die diere het ook minimale effekte gehad op die proksimale komposisie as ook mioglobien inhoud van die spiere wat geanaliseer was. Daar was klein verskille vir die proksimale komposisie tussen die verskillende spiere waargeneem. Hierdie verskille kan wees as gevolg van verskille in anatomiese ligging en dus die funksie van die verskillende spiere.

Die data deur hierdie navorsing gegenereer sal produsente en bemarkers van wildsvleis help met akkurate produksie, bemarking, etikettering as ook verbruiker opvoeding rakend rooibok vleis produksie.

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NOTES

The language and style used in this thesis is in accordance to the requirements of the journal of *Meat Science*. This thesis represents a compilation of manuscripts where each chapter is an individual entity and therefore some repetition between chapters, especially in the Materials and Methods section, was unavoidable.

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Chapter 1
GENERAL INTRODUCTION

1.1 BACKGROUND

In the past 58 years, the South African population has increased to approximately 56 million people and is expected to continue growing in the future (Statistics South Africa, 2018). An increasing population puts a strain on the agricultural sector to supply the ever-growing demand for nutritious and affordable food sources. The local demand for red meat and chicken cannot be met by South African producers, resulting in South Africa being a net importer of both these protein sources (Oberem & Oberem, 2016). Also, the influence of climate change is a threat to global food security and the availability of natural resources. It has been estimated that an increase in temperature of between 2.5°C and 5°C will result in the eradication of cattle farming and a vast reduction in sheep and goat farming in South Africa (Seo & Mendelsohn, 2008). Game species have, however, adapted to harsh climatic conditions and are better suited towards the environmental conditions of sub-Sahara Africa and can serve as a viable alternative to livestock production (Carruthers, 2008; Otieno & Muchapondwa, 2016). This has resulted in a shift from traditional livestock production to game farming in South Africa (Berry, 1986). It is estimated that game farms cover 16.8% of the total surface area of South Africa. Of the game ranches in South Africa, 50% are located in the Limpopo province, 20% in the Northern Cape and 12% in the Eastern Cape (Munzhedzi, 2018). The live sale of game animals contributed R1.7 billion to the South African economy in 2016. Trophy hunting contributed a further R1.7 billion in 2015 and local biltong hunting contributed R8.6 billion to the economy in 2015. The game industry also employs more than 100 000 people, mostly in the rural areas of South Africa where other employment opportunities are limited (Munzhedzi, 2018; Oberem & Oberem, 2016).

Modern-day consumers have also become more health-conscious and prefer a diet that is low in saturated fat, cholesterol and energy but that is still nutrient dense with high levels of protein, vitamins and minerals. Game meat meets all the above-mentioned criteria and has the potential to be the protein source of choice for health-conscience consumers. The intramuscular fat content of game species varies between 2.0 – 2.5 g/100g and the protein content between 20 – 24 g/100g of lean meat (Hoffman & Cawthorn, 2013). Apart from the health benefits, game meat in South Africa can be viewed as an organic and free-range product as the animals are reared extensively with minimal human interaction (Hoffman & Wiklund, 2006). Despite these positive attributes, consumers tend to view game meat as of poor quality; often associated with dry and tough meat (Radder & le Roux, 2005). Hoffman *et al.,*(2005) found that only 17% of the consumers interviewed listed game meat as a meat product that they prefer to buy. They also indicated that the price, quality and availability are the main limiting factors with regards to the purchasing of game meat. The consumers interviewed stated that they would be more likely to buy game meat if more information was available on the nutritional benefits as well as guidelines on how to prepare it. Various factors such as species, nutrition, animal age, sex and processing techniques can influence the structure and composition of skeletal muscles and thus the final meat quality (Listrat *et al*., 2015). These factors have, however, not been fully quantified in game species and this results in a large variation in quality and overall consumer acceptance. For game meat to be commercially established as an alternative protein source to commercial livestock, extensive research is needed on the meat quality and nutritional composition of game meat as well as the factors that might influence it (Cawthorn & Hoffman, 2014).

Impala are an ideal species for game meat production as they have a wide distribution, high fecundity rates and produce a high meat yield (Bourgarel *et al*., 2002; Hoffman, Kritzinger, & Ferreira, 2005). Impala are thus ideally suited towards continuous cropping regimes, with a culling rate of between 25 – 30% suggested for areas where no predation occurs (Fairall, 1983). The impala was the second most hunted species for trophies as well as consumptive purposes, resulting in a total income of R334 484 and R813 579 respectively in 2018 (Munzhedzi, 2018). The impala is also used extensively in breeding programs to produce colour variants such as the black impala (Taylor *et al*., 2016). Due to the nature of such breeding programs, a surplus of impala, especially the rams, are available for meat production. Despite extensive research that has been done on impala, the influence of animal age and sex has not been evaluated before.

1.2 RESEARCH AIMS AND OBJECTIVES

The aim of this study was to quantify the effect of animal age and sex on the meat production parameters of impala. This will aid producers in accurately selecting the ideal age group at which to harvest their animals to ensure high yield without adversely affecting the meat quality. The objectives were as follow:

1.2.1 Reviewing available literature on impala meat production and quality (Chapter 2)

1.2.2 Determining the effect of animal age and sex on the carcass yield of impala (Chapter 3)

1.2.2 Quantifying the effect of animal age and sex on the physical meat quality attributes of impala meat (Chapter 4)

1.2.3 Quantifying the effect of animal age and sex on the chemical composition of impala meat (Chapter 5)

The results obtained will provide baseline data that can assist producers as well as marketers on whether the above-mentioned factors need to be taken into account during impala meat production.

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CHAPTER 2
LITERATURE REVIEW

2.1 THE SOUTH AFRICAN WILDLIFE INDUSTRY

2.1.1 Background and history

In South Africa, the game industry plays a vital role in food security, job creation, ecotourism and conservation (Oberem & Oberem, 2016). Game ranching refers to the breeding, management and production of wildlife species on privately owned land. Game farming systems are either extensive or semi-intensive operations. Large areas in South Africa are arid or semi-arid regions with low rainfall, high evaporation rates and poor soil quality and of the available agricultural land in South Africa, 80% is classified as marginal land that is considered suitable for grazing only. According to Oberem and Oberem (2016), wildlife species are better adapted than livestock species to drought conditions.

During the early twentieth century, commercial livestock species were regarded as superior to game animals in terms of production. In order to preserve grazing for livestock and to prevent the transmission of diseases from wildlife to livestock, a large-scale eradication of South African wildlife species was carried out (Carruthers, 2008). Only in later years did producers realised that game animals are better adapted to the harsh, semi-arid environment of Sub-Saharan Africa than their domesticated counterparts are, and that they thrived in these challenging environments. The utilization of game species in areas less suitable for livestock production thus presents an opportunity to potentially supply the increasing need for sustainable protein in Africa (Carruthers, 2008).

The perception of farmers towards wildlife started to change during the 1960s, as South Africa experienced a period of drought, which consequently resulted in a decrease in beef production. Due to this shortfall in production, farmers invested in wildlife species that are more adapted to the harsh climatic conditions (Carruthers, 2008). The general cost of producing game extensively was lower than that of livestock due to production costs such as dipping, dosing and handling that were not needed or vastly reduced in game enterprises (Hopcraft, 2002). From an economic point of view, the transition from conventional livestock to game species helped improve the livelihood of South African farmers.

In 1991 the Game Theft Act, Act 105 was implemented. This was an important landmark for the game farming industry as it permitted the private ownership of game species (Oberem & Oberem, 2016). Game species were now considered as another type of commodity and this increased the number of game animals on farms, which had a positive effect on the conservation status of certain endangered or threatened game species. Since 1991, the number of game farms has increased, and it is estimated that there were more than 5000 operational game farms during the year 2000

(Carruthers, 2008). In 1998 it was estimated that game farms in the Northern Province (the current Limpopo Province) covered an area 2.92 million ha in size, which made up roughly 26% of the province’ s total surface area, with only 2.4% of the province being encompassed by nature reserves. The annual turnover for game ranches in the Northern Province during 1998 was approximately R221 million. The largest proportion of this income was generated by hunting activities, followed by live capture and sales of game species, eco-tourism and lastly meat production (Van der Waal & Dekker, 2000). Currently, wildlife ranches in South Africa encompass 16.8% of the country's total surface area. There are more than 9000 commercial or privately-owned game farms operating in South Africa with the majority being in the Limpopo province. The game industry has an estimated total revenue of R10.1 billion per year (Munzhedzi, 2018).

Wildlife ranching, wildlife activities and wildlife products form the three sub-sectors that the game industry comprises of. Wildlife ranching consists of game breeding and the live sale of animals. Wildlife activities are the viewing of wildlife (eco-tourism), biltong hunting as well as trophy hunting. Wildlife products entail game meat production and processing, the production of skins and hides as well as the production of other items such as curios (Munzhedzi, 2018). Historically, hunting formed part of the practice to eradicate game in areas where livestock farming was favoured. In more recent times, hunting started to play a vital role in the conservation of game species and is now considered to be the foundation that the game industry is based on. It is estimated that there are 200 000 local biltong hunters and approximately 6000 trophy hunters in South Africa. Political and economic instability in other African countries has promoted South Africa as a prime hunting destination for overseas travellers. The contribution of hunting towards the South African economy is wider reaching than just the revenue made through the hunt itself. Hunting supports a wide range of industries ranging from taxidermy, hotels, transport, and related tourism activities (Oberem & Oberem, 2016). It is estimated that between 60 – 70% of the revenue made through hunting is from secondary products and services (Munzhedzi, 2018). The hunting industry supports in excess of 140 000 jobs in South Africa, mainly in rural areas that have otherwise limited employment opportunities. The cornerstone of wildlife ranching is the breeding and live sale of wildlife species. Game breeding allows for the breeding of high genetic merit animals to either be hunted as trophy animals or for the breeding of replacement animals to stock game farms. Breeding has also been incorporated as a conservation tool to increase the numbers of rare or endangered species as well as species that are free of diseases such as tuberculosis and brucellosis (Oberem & Oberem, 2016).

Experts have expressed concern regarding the future of eco-tourism, live capture and sales of game animals. They predict that these two sectors might reach saturation point in the near future. More attention should thus be invested in expanding the market for meat production (Carruthers, 2008). This will allow farmers to diversify their farming operations to be more resilient towards changes in the market.

Consumers have recently become more health-conscious and this directly influences their food choices. Due to the perception that red meat is high in saturated fat and contributes to high blood pressure and coronary heart disease, the consumption of red meat has declined (Hoffman & Wiklund, 2006). However, game meat is low in saturated fat and high in polyunsaturated fats making it a lean and healthy alternative to beef. What sets game meat and venison (referred to as farmed deer) apart is that game animals are free-roaming and not domesticated. Game meat can be seen as an organic product as it complies with organic regulations. The above mentioned are all factors that promote the utilization of game meat as a truly South African protein source (Hoffman & Wiklund, 2006).

Historically, more game meat was exported than what entered the local market. In 2005 it was estimated that South Africa exported 160 000 deboned game carcasses. According to Hoffman & Wiklund (2006), the majority of these carcasses consisted mainly of springbok (*Antidorcas marsupialis*), blesbok (*Damaliscus pygargus phillipsi)* and kudu (*Tragelaphus strepsiceros*). In 2011, a ban was placed on South African exports due to the outbreak of Foot and Mouth Disease (Taylor *et al.,* 2016*),* which resulted in the loss of the export market for the next five years. During this time more than 700 jobs were lost (Oberem & Oberem, 2016). It is estimated that South Africa currently exports between 600 -2000 tons of game meat per year, valued at between approximately R60 – R200 million, although within the past month there has been a fresh outbreak of Foot and Mouth disease which will most probably result in the export market being closed once more. Western Europe however, consumes almost 100 000 tons of venison each year, which is mainly imported from New Zealand. An opportunity thus exists for South Africa to increase its exports of game meat to European countries (Munzhedzi, 2018) if they can overcome the issues around the foot and mouth disease. In addition, due to this volatile export market, the game meat industry needs to also focus on the local market and create a market awareness amongst consumers of the health benefits of game meat.

Due to the competitive nature of the red meat industry in South Africa, more science is required to guide the industry into ensuring that they meet the modern consumers' need. Consumers see game meat as a health food commodity - due to high protein and low intramuscular fat and cholesterol levels - which has led to increased demand for fresh game meat (Daszkiewicz *et al*, 2012; Hoffman & Wiklund, 2006). However, there is a lack of knowledge on the extrinsic and intrinsic factors that influence game meat quality; as the consumer expects the game meat quality to be similar, or superior to that derived from domesticated livestock (Wassenaar, Kempen, & van Eeden, 2019). Some of these factors such as age, sex and nutrition can be controlled by the producer.

2.2 THE IMPALA (*Aepyceros melampus*) AS A MEAT-PRODUCING ANIMAL

The impala is the most common antelope of the Bushveld regions of South Africa. The impala is characterized by a fawn-coloured coat, with white underparts, and measures approximately 900 mm at the shoulders (Skinner & Smithers, 1990).

2.2.1 Habitat and distribution

Impala are distributed throughout East Africa to South Africa (Figure 2.1). The impala, *Acepyceros melampus*, consists out of three subspecies. The Southern impala (*A. m. melampus*), Black-faced impala (*A. m. petersi*) and East African impala (*A. m. remdilis*). Molecular genetics has however proven that only the black-faced impala (*A. m. petersi*) and the common southern impala (*A. m. melampus*) are true sub-species (Nersting & Arctander, 2001). The Southern impala will be the focus of this study.

The impala was first documented in 1805 by the German zoologist, Lichtenstein, when he came across impala close to the town Kuruman in the Northern Cape Province of South Africa. This, however, represents the most southwest distribution of impala and impala tend to occur more densely from northern Kenya downwards to north-eastern South Africa.

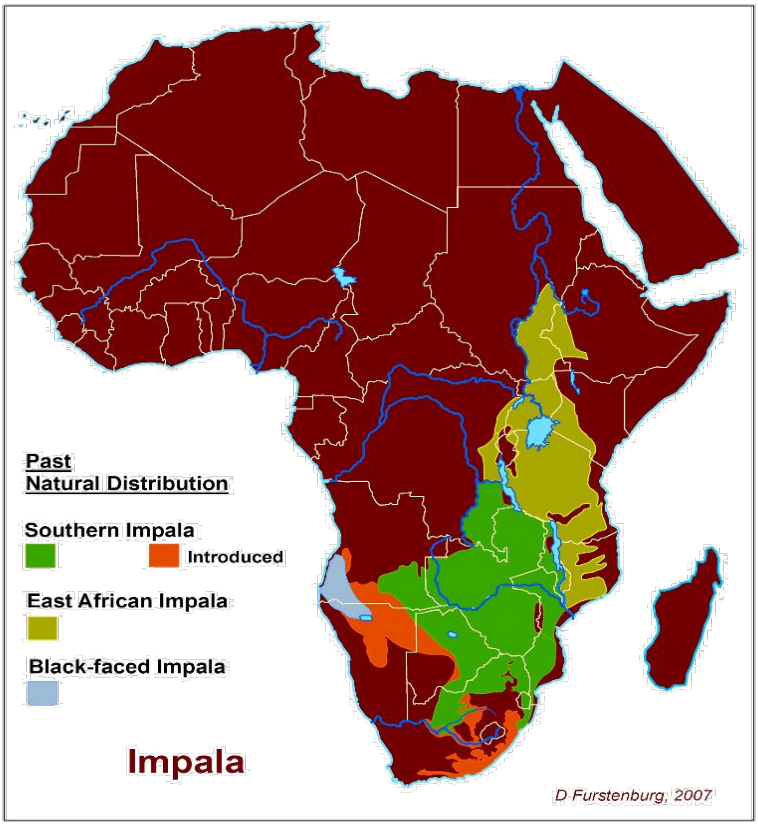

Figure 2.1. Natural distribution of impala (*Aepyceros melampus*) throughout southern Africa (Furstenburg, 2016).

Due to the browsing habit of impala, they prefer a bushveld or savannah habitat that is rich in tree and shrub species and the rainfall associated with these habitats range from 400-700 mm annually. Impala tend to avoid rocky and mountainous areas, forests, open grassland as well as very arid environments (Averbeck, 2002; Furstenburg, 2016; Young & Wagener, 1968).

2.2.2 Growth and development

Adult males measure approximately 0.9 m at the shoulder and have an average live weight of approximately 50 kg. The females are smaller with an average live mass of 40 kg. However, the average mass differs from region to region (Skinner & Smithers, 1990).

Ewes reach maturity at two years of age at 75% of the total body mass, and growth plateaus at approximately five years of age (Figure 2.2). At maturity, ewes have a fecundity rate of 95% (Fairall, 1983). The peak lambing period for impala in southern Africa varies between September and October and will continue up until January of the following year (Dasmann & Mossman, 1962). The average gestation period for impala varies between 185 to 205 days and lambs are kept in large nursery groups and only interact with their mothers during feeding times (Furstenburg, 2016). According to Hanks *et al,* (1976) the average age at which impala rams start spermatogenesis is 1.5 years. The testes, however, continued to grow up until four years of age. The growth curve of male impala plateaus at approximately four to five years of age (Brooks, 1978). The natural lifespan of impala varies between eight and twelve years depending on the environmental conditions (Furstenburg, 2016).

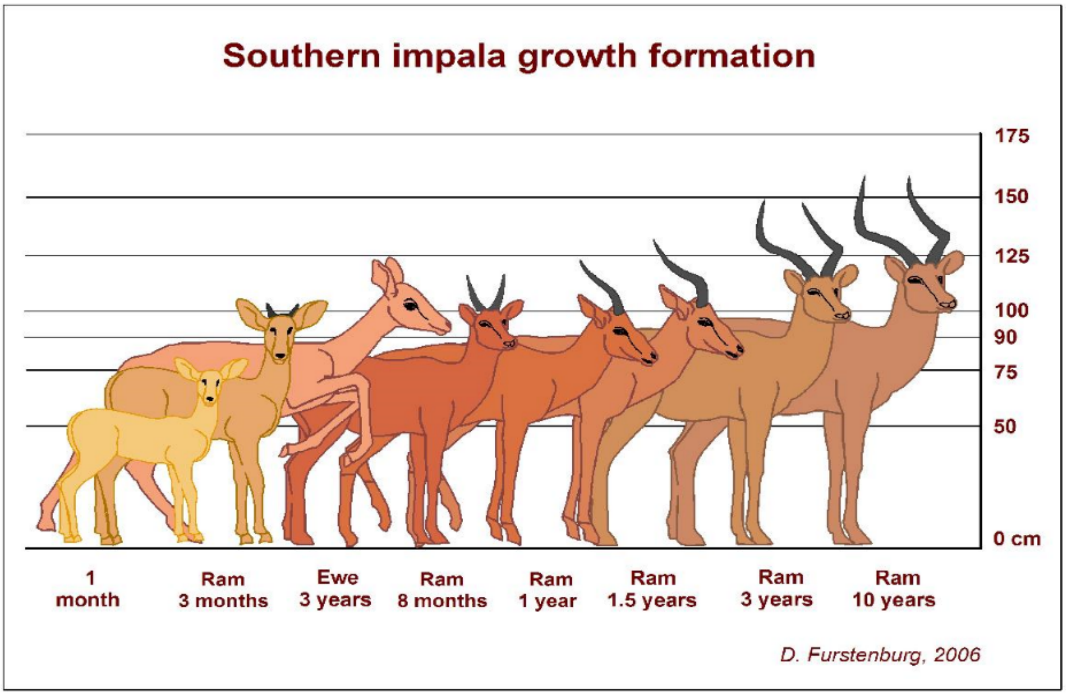

Figure 2.2. The southern impala (*Aepyceros melampus*) growth formation (Furstenburg, 2016).

2.2.3 Horn growth

The horn growth potential of impala rams is one of the main factors that the selection of breeding rams are based upon and this selection usually happens at approximately one and a half years of age (Furstenburg, 2016). Horn growth is most active at one and a half years and continues to grow until a maximum is reached around four and a half years of age. As the impala ages, the tips of the horns will start to wear down and the horns become progressively shorter. As seen in Figures 2.2 and 2.3, the growth at the base of the horn follows an uneven pattern of growth, resulting in the characteristic angled spiral associated with impala (Spinage, 1971). The number of grooves on an impala's horn gives an indication of the animal's age and is frequently used for age determination. Only rams have well-developed horns, but ewes can sometimes have small, deformed horns. Trophy status according to the Rowland Ward, is $23\frac{5}{8}$ inches or approximately 60 cm or greater, which is usually only reached after five years of age (Furstenburg, 2016; Roettcher & Hofmann, 1970).

Figure 2.3. Horn growth of the impala with age (Furstenburg, 2016)

2.2.4 Seasonal changes

The impala exhibits a clear sexual cycle with peak sexual expression during the rut or mating season, which stretches over a month-long period, usually from the middle of May to mid-June (Dasmann & Mossman, 1962). During this period, the size of the reproductive organs and body condition of the impala will fluctuate. The testes weight will increase to a maximum two weeks before the commencement of the rut. The weight, however, starts to decline after the rut, but spermatogenesis will continue throughout the year despite the decrease in size (Hanks *et al.*, 1976; Skinner, 1971). Along with the change in sexual organs, the overall body condition of the rams also fluctuates in accordance with this period. Hormone secretion is stimulated by a decrease in daylight hours leading up to the rut, resulting in the laydown of fat in the neck of male impala. This enlargement of the neck of rams leads to the triggering of oestrus in ewes (Skinner, 1971). Rams exhibit fighting behaviour as a show of dominance before and during the time of the rut leading to a decrease in body condition as more energy is expended and less time is attributed to foraging (Skinner, 1971). The nutritional value of the veld also declines in the period after the rut resulting in further body mass loss (Skinner, 1971); Brooks (1978) recorded a decrease in body mass of rams from 62.4 kg to 54.5 kg between February and July.

2.2.5 Potential for meat production

The impala's wide distribution in southern Africa, its relative abundance and high fecundity rates make it well suited to continuous cropping for game meat production regimes (Bourgarel *et al.*, 2002; Fairall, 1972; Hoffman, Kritzinger, & Ferreira, 2005; Taylor *et al.*, 2016). Impala are able to utilize the large tree and shrub component of the South African bushveld very effectively because of their browsing and grazing habits (Fairall, 1983). A male to female ratio of 1:10 has been suggested for impala populations to ensure optimum breeding without adversely affecting fecundity rates which can be achieved through culling excess males and all females older than three years after they have weaned their young (Fairall, 1985). Fairall, (1983) has suggested an annual culling rate of 22% if predation is present and 25-30% if no predation occurs. Impala meat harvested in Uganda showed good marketing potential; fresh meat was sold to butcheries and restaurants as either whole or processed cuts. The top-selling products were sirloin, fillet, rump and topside. It was calculated that a revenue of US$ 53 for whole carcasses and US$ 82 for processed cuts were made (Averbeck, 2002), these prices are dated and it is expected that the present income will be substantially higher.

2.3 GROWTH

Growth is defined as the increase in weight or dimension of an animal until a mature size is reached, and development is defined as the changes in body conformation and function to aid in the physiological needs of the mature animal (Jones, 2004; Lawrie & Ledward, 2006). An increase in weight is deemed a reliable measure for growth and is widely used due to its ease of measurement. When live weight is recorded over time, a sigmoidal or "S" shaped growth curve is obtained. The point of inflexion represents the phase of maximum growth and the plateau where the animals reach maturity and a point of saturation is obtained. The sigmoidal growth curve is similar for most species, varying only in the time needed to reach the plateau (Jones, 2004).

2.3.1 The allometry of growth

The sequence at which body parts develop is related to the importance of that part to the survival of the animal at that time; critical organs and muscles needed for initial survival, such as the brain, heart and lungs, will thus develop before the skeletal muscles (Jones, 2004; Lawrie & Ledward, 2006; Berg & Butterfield, 1976). The ratio of bone: muscle: fat also adheres to this sequence of development. Bone development is of high importance during prenatal development as this provides the skeletal framework needed for further development, but bone growth decreases in comparison to muscle growth postnatally. Muscle development increases in the postnatal phase in comparison to bone until a saturation point is attained and fat deposition commences. Lastly, fat requires a substantial amount of energy to be synthesised and does not fulfil a critical role during the beginning stages of life. It is thus the last tissue to be deposited and serves as an indication of physiological maturity (Jones, 2004; Lawrie & Ledward, 2006). As the animal matures, muscle growth decreases with the coupled increase in fat production. A point of biological and economic inefficiency is reached when the energy requirements to further lay down fat as well as to maintain the body outweighs the gains achieved. It is thus important to determine the ideal slaughter age that ensures the highest yield whilst remaining a viable economic endeavour (Berg & Butterfield, 1976).

However, farmers and/or producers are not paid based on live weight but rather on the carcass weight obtained. If the number of unsellable parts of the animal (head, feet, some of the organs etc.) are unknown, live weight can be a deceptive indication of yield. Carcass weight is thus a better parameter to use for the calculation of yield obtained. The difference between live weight and carcass weight can also be expressed as a percentage, known as the dressing percentage of the animal. Dressing percentage is calculated by dividing the warm carcass weight by the live weight and expressed as a percentage. Animals with a high dressing percentage will thus yield a high proportion of sellable meat (Lawrie & Ledward, 2004; Berg & Butterfield, 1976).

2.3.2 Von Bertalanffy growth equation

Growth curves are a useful tool in determining the meat production potential of a species, and can also be used to calculate the most economical age at which to slaughter an animal or to determine the approximate age of an animal if the weight is known (Fairall, 1983; Von La Chevallerie, 1970). The first growth equation for impala was calculated by Howells and Hanks, (1975) who collected data on 151 male and 181 female impala from the Wankie National Park in Zimbabwe. A theoretical Von Bertalanffy growth equation was used to describe the increase in growth with age. According to this equation, male impala will reach their asymptotic mass of 56.6 kg at roughly 54 months of age and female impala will reach their asymptotic mass of 43.2 kg at roughly 36 months of age. Von Bertalanffy growth equations were also used by other authors to determine the growth curve of impala (Table 2.1).

As seen in Table 2.1, the asymptotic age of male impala varied between 4 and 5 years depending on the geographical location. The differences due to the location can be as a result of different veld conditions and thus available nutrients. When evaluating the theoretical weights obtained from Howells and Hanks (1975), 76% of the asymptotic weight is reached at 18 months, 92% at 30 months and 97% at 42 months. It is evident that the growth rate declines as the age increases. Culling male impala at 18 months can be advised as the growth rate and feed conversion efficiency is higher than that from its older counterparts. The data obtained is however only from four different locations and is dated (varies between 41 and 33 years ago), so is thus somewhat limited. Breeding programs tend to select for an increase in size and body weight. New growth curves are thus needed to determine if breeding programs have altered the asymptotic weight for impala rams. Growth curves for female impala from various locations are also needed.

Table 2. 1 Theoretical Von Bertalanffy growth equations, asymptotic ages and weights at different ages of male impala, adapted from Engels (2019).

Location	n	Equation	Asymptotic age (years)	Asymptotic weight (kg)	18-month weight (kg)	30-month weight (kg)	42-month weight (kg)	Reference
Wankie National Park, ZI	181	$W_t = 56.6(1-e^{-1.13(t+0.68)})^3$	4.5	56.6	43.3	52.1	55.1	Howells & Hanks (1975)
Sengwa Wildlife Research Area, ZI	170	$W_t = 59.58(1-e^{-0.95(t+0.83)})^3$	5	59.6	42.1	52.3	56.7	Hanks *et al.* (1976)
Mkuzi Game Reserve, RSA	182	$W_t = 58.2(1-e^{-0.728(t+1.127)})^3$	4	58.2	36	46.6	52.4	Brooks (1978)
Kruger National Park, RSA	-	$W_t = 48.2(1-e^{-0.728(t+1.127)})^3$	5	48.2	29.8	38.6	43.4	Fairall (1983)

ZI = Zimbabwe, RSA = Republic of South Africa, W_t = Weight in kg, t= age (years)

2.3.3 Stocking density

The stocking density of a specific area of land refers to the number of animals kept on that surface area at any given time. The aim is to keep the stocking density below the ecological carrying capacity at all times to ensure sufficient grazing and browsing. The stocking rate, however, refers to the number of animals that the farmer or producer decides on allocating to a specific area of land. Stocking rates are usually given as animal units per hectare per year (Bothma & du Toit, 2010). Determining the stocking density and thus the accompanying stocking rate is a critical tool in veld management practices. Another important aspect to consider when calculating these rates is whether the animals are pure browsers, grazers or mixed feeders, and the proportion of the diet for the latter, although this is also known to differ with season.

According to the Dekker (1997), one browser unit (BU) can be represented by the browsing capacity of one kudu and one grazer unit (GU) can be represented by the grazing capacity of one blue wildebeest. The metabolic weight is used in the browser and grazer unit calculations to be able to compare animals of different sizes based on their energy requirements. It is possible to calculate the browsing and grazing units of other species based on the following calculation:

$$GU = \frac{180^{0.75}}{(mean\ body\ mass\ of\ species\ x)^{0.75} * (Total\ combined\ overlap\ with\ blue\ wildebeest)}$$

$$BU = \frac{140^{0.75}}{(mean\ body\ mass\ of\ species\ x)^{0.75} * (Total\ combined\ overlap\ with\ kudu)}$$

In the equation, the values of 180 represents the average weight of a mature blue wildebeest and 140 the average weight of a mature kudu, respectively. As impala are mixed feeders; grazing and browsing, it is necessary to use both equations for the calculations to determine the capacity. The total combined overlap for impala with blue wildebeest and kudu have been calculated as 0.385 and 0.304, respectively (Dekker, 1997). If the theoretical weights obtained by Howells & Hanks, (1975) from Table 2.1 are used, the following GU and BU will be obtained for impala of different ages within each production system (Table 2.2). For the 30- and 42-month production system the average weight between the different age groups of each system was used to account for the weight difference between the different ages.

Table 2.2 Impala browser and grazer units per production system

	Production system		
	18-months	**30-months**	**42-months**
Weight (kg)	43.3	(52.1 + 43.3)/2	(55.1 + 52.1 + 43.3)/3
BU	7.93	7.38	7.10
GU	7.56	7.03	6.77

BU = browser unit, GU = grazer unit

The grazing capacity of one blue wildebeest is thus similar to the grazing capacity of approximately eight, 18-month-old impala or to a combined herd of seven animals consisting of both 18 and 30-month-old animals as well as a combined herd of approximately six animals consisting of both 18-, 30- and 42-month old animals. The area studied by Dekker (1997) was located on a game ranch in the Limpopo province, 20 km west of the town Messina, South Africa. For that given area, a grazing capacity of 4.4 GU/100 ha and 5 BU/100 ha was estimated. If the grazing capacity is the limiting factor, the GU can be used to determine the stocking density required and *vice versa* for browsing.

Game ranch management has developed over the last decade into an industry that employs sound scientific principles, similar to that of traditional livestock farming, to ensure optimum production. Through accurate record-keeping in the controlled breeding camps, the offspring can be weaned into dedicated grow-out camps based on age and sex; a practice that has become possible for large breeding operations. It is thus possible to wean the offspring and allocate them to a specific camp where after they can be culled at a specific age. It is thus important to consider not only animal numbers but also animal age when determining the stocking density of an area. Older and larger animals need more resources to sustain (higher maintenance requirements) themselves in comparison to younger and smaller animals. This is an important factor to consider when deciding on a management plan aimed to ensure the highest yield (kg meat) per area. To illustrate this principle and for the ease of calculation, a 500 ha grower camp was used to determine the theoretical yield of different production systems. The number of impala presented in Table 2.3 can be kept per age group (rounded down to the nearest animal) to make up a herd to ensure maximum carrying capacity per production system. As Van Zyl, Von La Chevallerie, & Skinner, (1969) calculated the dressing percentage of impala at 58%, this value will be used in determining the kg meat yield in the example below.

Table 2.3 The maximum number of impala per 500ha production system, rounded down to the nearest animal

	Production system		
	18-months	**30-months**	**42-months**
Number of animals	165	154	148

To ensure that the stocking density limitations are not exceeded, the number of animals should be stocked from the start with the end number of animals in mind (Table 2.4). Thus, for the 30-month system, a maximum of 77 weaners (6-months old) can be started with. After one year another 77 weaners can be added to the system. By the end of year two there will be 77, 30-month old animals and 77-, 18-month old animals and thus not exceeding the limit of 154 animals at any given time. The same applies to the 42-month system, but only one-third of the maximum number of animals can be started with because by year three there will be equal numbers of all three age groups within the production system. The number of yearly replacement weaners added to the 42-month production system will be less than in the all-in-all-out 18-month production system due to stocking density limitations. The number of ewes and rams needed to produce the replacement offspring will also be less in the 42-month production system than the 18-month system. The above-mentioned numbers are estimates and do not take, for example, natural mortalities into account.

The yearly carcass yield will be as follow for each production system (Table 2.4):

Table 2.4 Total yield (kg calculated from a 58% carcass yield) over a four-year period for the different production systems

	18-month system	30-month system	42-month system
Carcass yield year 1	165 x 43.3 x 0.58 = 4143.81	0	0
Carcass yield year 2	165 x 43.3 x 0.58 = 4143.81	77 x 52.1 x 0.58 = 2326.79	0
Carcass yield year 3	165 x 43.3 x 0.58 = 4143.81	77 x 52.1 x 0.58 = 2326.79	49 x 55.1 x 0.58 = 1565.94
Carcass yield year 4	165 x 43.3 x 0.58 = 4143.81	77 x 52.1 x 0.58 = 2326.79	49 x 55.1 x 0.58 = 1565.94
Total yield over 4 year period	= 16 575.24 kg	= 6 980.28 kg	=3 131.88 kg

It is thus clear that at the end of year 3 when the system is fully productive that the meat yield per fixed surface area for the 18-month system is substantially higher than both the 30- and 42-month systems. There are also other advantages such as a larger breeding population which will increase the selection pressure for characteristics such as horn growth and pelt colour. Another advantage is that the 18-month system will yield a higher number of skins and offal which could increase the secondary income. Also, having a higher number of animals processed by the abattoir at a given time will decrease the costs per unit applicable to running the abattoir. Although not yet researched, all indications are that the younger animals will also yield a more superior meat quality.

In the system described above, the harvesting rate implies the removal of 100% of the selected aged animals. However, there are more extensive systems where different aged rams and ewes are kept and then different harvesting rates will need to be employed.

2.3.4 Harvesting rates

To effectively utilize game species for meat production, a sustainable harvesting program needs to be established. Such programs will entail the culling of animals without causing a continuous decline in the population. Harvesting can also be used as a mechanism to stimulate population growth without exceeding its ecological capacity. The majority of wild ungulate populations have a surplus of adult and sub-adult males within the population; the selective harvesting of these surplus males will increase the productivity of the herd due to more resources being available for the productive females. It is however important that enough reproductively active males remain in the population to ensure successful breeding. The population structure of animals shows variation due to seasonal breeding and unforeseen losses as a result of droughts or other unexpected environmental conditions. Periodic harvesting is thus advised that can adapt to variation in population structures.

The harvesting rate can now be calculated based on the number of animals left in the population in comparison to a fixed annual rate. Accurate record-keeping is however needed on the number of births and deaths that occur. To determine the exponential growth rate of a population over a given time, the following equation is applicable:

$\bar{r} = \sum Nt - [(\sum Nt)(\sum Nt) / n] / \sum t^2 - [(\sum t)^2 / n]$

Where:

$\bar{r}$ = mean exponential growth rate

n = number of counts

N = $\log_e$ amount of animals in each count

t = time interval

Σ = sum of

The growth rate obtained from this equation can be used to determine the harvesting rate. The choice of harvesting rate will be determined by the end objective of the population dynamics. If the aim is to keep the population stable (births=deaths) then the harvesting rate will be equal to the growth rate of the population (Bothma & du Toit, 2010).

2.4 MEAT QUALITY

According to Wassenaar, Kempen, & van Eeden, (2019) consumers list availability, sensory characteristics, production ethics and associated health benefits as the key attributes that influence their choice on whether or not to consume game meat.

The perceived quality of meat is one of the main factors behind the purchase and consumption of meat products. Consumers base meat quality on visual cues at purchase as well as the eating quality after purchase. It has been noted that consumers of different backgrounds and cultures have different preferences and standards when it comes to evaluating meat quality (Lawrie & Ledward, 2004). It is, however, important to assess the underlying factors that could influence perceived quality.

At the point of purchase, the consumer relies on visual cues to indicate potential quality. This includes colour, drip loss and the amount of visible fat (Troy & Kerry, 2010).

2.4.1 Colour

Consumers associate a bright red colour with wholesomeness and freshness and will thus favour meat products with this visual appeal (Dikeman & Devine, 2004). It is thus important to evaluate the factors that could influence the colour of meat products (Neethling *et al.,* 2017).

Colour is objectively measured through the CIE L*a*b* system that obtains colour measurements through spectroscopy (Yam & Papadakis, 2004). The L* value refers to the lightness component and ranges from 0 to 100. The a* value represents the red and green scale. A positive value falls on the red axis and a negative value on the green axis. The b* value revers to the blue and yellow scale, with blue, indicated as positive and yellow as negative. These values provide an independent criterion upon which meat colour can be evaluated and compared (Kerry & Ledward, 2009).

2.4.2 Influence of myoglobin on meat colour

Myoglobin is a globular protein that is commonly known as the protein that gives meat its red colour. It is a cytoplasmic hemoprotein that consists of a single polypeptide chain of 154 amino acids (Ordway, 2004). Myoglobin is present in cardiac muscle cells as well as in oxidative skeletal muscle fibres and binds reversibly with molecular oxygen which it stores temporarily within the cell (Kendrew *et al.,* 1958). Myoglobin also aids in the transport of oxygen from red blood cells to the mitochondria during stages of increased metabolic activity. Oxygen binds to myoglobin through its heme residue (Cornforth & Jayasingh, 2004).

The total myoglobin content can be quantified through the spectrophotometric absorbance at a wavelength of 525 nm (Cornforth & Jayasingh, 2004).

Myoglobin can be present in meat in either of its three redox forms namely deoxymyoglobin (DeoxyMb), oxymyoglobin (OxyMb) and metmyoglobin (MetMb). The redox form that is produced relies on the ligand that is bound to the heme iron as well as the redox state of the iron. The iron can either be in the reduced (Fe^{2+}) or oxidized (Fe^{3+}) form. The iron present in myoglobin is highly susceptible to the binding of oxygen. Post-mortem oxygenation thus results in blooming (Cornforth & Jayasingh, 2004; Mancini & Hunt, 2005)

The redox states influence the colour of fresh meat and thus the consumer acceptability of the product. In DeoxyMb the iron present is in its reduced state (Fe^{2+}) with no ligand bound to the iron. DeoxyMb only occurs where no oxygen is present, for example, vacuum-packed meat or meat just post cutting. DeoxyMb is associated with a dark purple-red colour. Blooming occurs when DeoxyMb is exposed to oxygen and forms OxyMb through the proses of oxygenation. The iron present remains in the reduced state (Fe^{2+}), but diatomic oxygen is now bound to the ligand and is associated with an attractive cherry red colour. With prolonged exposure to oxygen, the depth of the OxyMb layer will increase until a saturation point is reached. The further oxygenation of OxyMb and DeoxyMb results in the formation of MetMb. The iron present is now in an oxidized ferric (Fe^{3+}) state. Water is bound to the ligand and an unattractive brown colour is formed (Cornforth & Jayasingh, 2004; Mancini & Hunt, 2005; Neethling *et al.*, 2017).

2.4.3 Meat tenderness

Tenderness and texture play a vital role in consumer perception of meat quality and overall eating enjoyment. Whilst colour forms the major deciding factor for the initial purchase, tenderness will determine if a consumer will buy the product again (Kerry & Ledward, 2009). The amount of connective tissue, the length of the sarcomere as well as the extent of post-mortem breakdown of myofibrillar protein are the main factors that dictate meat tenderness (Kerry & Ledward, 2009). Of these aspects, the connective tissue present in muscle and meat forms the backbone of tenderness determination and variation (Astruc, 2014). It is thus important to understand the core principles and underlying factors that have an influence on connective tissue structure.

Connective tissue is found throughout the animal's body and gives form and strength to organs as well as connects different tissues to one another. There are different types of connective tissue namely, elastic-, reticular-, collagenous-, adipose tissue as well as bone and cartilage (Frandson *et al.*, 2009). Collagen is produced through fibroblasts that produce long protein like fibres that have significant tensile strength. Collagen is classified as a structural protein that contributes to 30% of the protein found in an animal's body (Frandson *et al.,* 2009).

2.4.4 Influence of animal age on meat quality

The main physical characteristic of meat that is influenced by age is the tenderness. As an animal ages, the meat becomes progressively tougher and the value thereof decreases, as consumers prefer tender meat and are willing to pay a premium for it (Purslow, 2005; Troy & Kerry, 2010). Meat tenderness is influenced by the quantity and solubility of the connective tissue. Ngapo *et al.,* (2002) have shown that collagen influences the tenderness of meat during cooking. The solubility of collagen plays a role in the perception of the toughness of cooked meat. The collagen in meat derived from young animals is more soluble than that of older animals; insoluble collagen in older animals is linked to the decreased rate of synthesis of new collagen. This gives the collagen time to stabilize and form fixed, thermal stable crosslinks that are insoluble (Shimokomaki, Elsden, & Bailey, 1972). Due to this slow turnover rate of collagen, slow modifications to the collagen structure takes place. This enables the crosslinks between collagen molecules to change from a divalent to a trivalent structure, increasing the thermal and mechanical stability (Purslow, 2005).

This was also illustrated by Shorthose & Harris, (1990) who evaluated the tensile strength of different muscles from beef animals of different ages. They found that increasing age had a highly significant negative effect on meat tenderness.

Meat colour is also influenced by age, with older animals having darker (lower L* values) and redder (higher a* value) meat due to the concentration of myoglobin increasing with age (Neethling *et al.,* 2017). For game species this was noted in adult and sub-adult impala and kudu, harvested in the Limpopo region of South Africa; adult males had a lower L* value in comparison to sub-adult males (Hoffman *et al.*, 2009)**.**

2.4.5 Influence of sex on meat quality

Male animals tend to have darker meat in comparison to female animals (Seideman *et al.,* 1982) due to increased levels of myoglobin. This could be due to male animals being more physically active in comparison to female animals (Neethling *et al.*, 2017). It is also assumed that the meat from intact males is tougher than that of female animals. This was confirmed by Cloete, Hoffman, & Cloete, (2012) who noted that in sheep, intact rams had a 9% higher shear force readings for the *m. longissimus* muscle in comparison to ewes. This could be due to the rams exhibiting an increased level of activity, especially pre-slaughter. This was also observed in the difference final pH where the rams showed significantly higher pH readings in comparison to the ewes. According to Vergara, Molina, & Gallego, (1999), the meat of female sheep had a lower water holding capacity and thus a greater tendency to release water than that of rams. This could lead to the meat of the ewes initially being juicier than that of the rams.

2.5 CHEMICAL COMPOSITION OF MEAT

The chemical composition of meat aids producers in accurate labelling, marketing and consumer education (Williams *et al.,* 2006). The main components that meat consists of are moisture, protein, fat, carbohydrates and ash (Keeton & Eddy, 2004). Lean red meat is generally low in fat, high in biologically available protein and contains many essential vitamins and minerals needed for human health (Williams, 2007). Apart from the fat content, the nutritional composition of meat stays relatively stable despite the influence of breed, age, sex, housing and feeding (Bender, 1992). Health-conscious consumers prefer lean meat, making game meat an attractive alternative to traditional livestock species (Wassenaar *et a*l., 2019). The fat content of game species varies between 2.0 - 2.5 g/100 g lean meat in comparison to traditional livestock having a fat content of between 2.8 – 4.7 g/100 g lean meat. Traditional livestock species do, however, also have a large amount of subcutaneous fat, which in most cases are absent in game species (Hoffman & Cawthorn, 2013; Williams, 2007). The moisture content of meat makes up the largest proportion ranging from 75-80% of the cell mass post-mortem. Water forms a major part of the structural composition of sarcoplasm as well as surrounding the myofibrillar proteins (Keeton & Eddy, 2004). The protein content of red meat varies between 20 – 25 g/100 g raw meat and has a high bioavailability in comparison to protein derived from plant sources, as well as all the essential amino acids needed for protein synthesis without containing any limiting amino acids (Williams, 2007). The mineral content of meat comprises of cellular components, bone or any ingredients such as sodium chloride that could be added to the meat during processing. The ash content of meat represents the total mineral content present in the meat. The ash content of game species varies between 1.0-2.4 g/100 g. (Hoffman & Cawthorn, 2013; Keeton & Eddy, 2004)

2.5.1 Influence of age on chemical compositions

As the animal ages, the composition of the muscles will vary as a result of the increase in body weight and muscle development. The protein content will reach its maximum at ~5 months of age, whereas the non-protein nitrogen will continue to increase till ~12 months of age (Lawrie & Ledward, 2006). As animals age, the concentration of myoglobin present in the meat will also increase. This increase happens in two phases: an initial rapid rate of increase followed by a more gradual rate of increase. This two-phase increase links with the increase of enzyme activity that is involved in respiration and ultimately energy production as the animal grows (Cho *et al.,* 2015; Humada, Sañudo, & Serrano, 2014; Kim *et al.,* 2012; Lawrie & Ledward, 2006). The intramuscular fat content also increases with age, with a corresponding decrease in moisture content. This was noted in both fallow deer and springbok, with older animals having a higher intramuscular fat content and lower moisture content in comparison to younger animals (Hoffman, Kroucamp, & Manley, 2007; Volpelli *et al., 2003)*

2.5.2 Influence of sex on the chemical composition

Female animals have a higher proportion of intramuscular fat in comparison to intact males. Despite the low IMF content of wild ungulates, female animals still exhibit an increased level of fat in comparison to male animals (Lawrie & Ledward, 2006; Ledger, Sachs, & Smith, 1967). This difference has been noted in domesticated roe deer as well as in free-roaming blesbok, springbok and impala (Daszkiewicz *et al.*, 2012; Van Zyl & Ferreira, 2004). The myoglobin content of meat is also influenced by sex. Due to increased levels of activity associated with fighting and breeding, male animals tend to have a higher concentration myoglobin present in their meat in comparison to female animals. (Neethling *et al.*, 2017; Seide *et al.*, 1982).

2.6 CONCLUSION

Impala are a well-adapted species that is ideal for meat production; they have a high fecundity rate, wide distribution and favourable meat quality. Game meat also serves as a viable alternative to traditional livestock species, which have significant health benefits and are low in fat and high in protein making it a highly suitable choice for health-conscious consumers. This has resulted in impala attracting significant research attention, mostly focused on growth, nutrition and reproduction. Studies focusing on the meat quality and yield of impala have focused on the LTL muscle whilst age has only been defined as adult and sub-adult classes. Nonetheless, significant differences have, however, been found between ages as well as between specific muscles. To expand the game meat industry, accurate baseline data is needed on game meat and the factors that influence it. Fortunately, the modern game farm, focused on breeding animals with specific traits requires accurate recording of factors such as age and sex, this creates an opportunity to more accurately evaluate the effect of these two factors on the yields and meat quality of impala. Therefore, this research will quantify the influence of animal age and sex on the meat production potential, meat quality and chemical composition of impala meat.

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CHAPTER 3

INFLUENCE OF AGE AND SEX ON THE CARCASS YIELD OF IMPALA (*Aepyceros melampus*)

ABSTRACT

This study aimed to determine the influence of age and sex on the meat and offal production potential of impala. A total of 32 impala were harvested from the Mookgophong area in Limpopo, South Africa. The animals were grouped according to age and sex and consisted of 24 rams and eight ewes. The rams were divided into three different age groups: 42-, 30- and 18-months old, each age group containing eight rams. All eight ewes were 30-months old and were compared to the 30-month-old rams. Of all the age groups, the 42-month-old rams had the heaviest carcass (34.1 ± 4.03 kg), muscle weights and offal yields. However, when different management scenarios are taken into account, the 18-month-old rams produced the highest annual meat yield (1960 kg p.a.) compared to scenarios where older animals were culled. The 30-month-old rams also had a higher carcass weight (28.3 ± 1.52 kg) than the ewes (23.5 ± 2.2 kg). The baseline data recorded in this study will aid producers in deciding upon which age to cull their impala at for optimum meat production.

Keywords: age, impala, meat production, sex

3.1 INTRODUCTION

The South African population has grown from approximately 1.7 million people in 1960 to 57.7 million people in 2018 (Statistics South Africa, 2018). This has resulted in an increased demand for nutritious, sustainable and affordable protein sources. At present, South Africa cannot satisfy this demand from local production and is a nett importer of both red meat and poultry. Achieving nutrition security amidst challenging economic times is thus a major concern for the South African agricultural sector (Oberem & Oberem, 2016).

Game meat production is a viable alternative to aid in the supply of protein to the ever-growing market. Game meat is a sustainable, free-range and organic product (Hoffman & Cawthorn, 2012). According to Van Zyl and Ferreira (2004), game species also have a better meat production potential due to the higher dressing percentages and low levels of fat compared to domestic livestock. In addition, game species are better adapted to the arid conditions in South Africa than domestic livestock (Oberem & Oberem, 2016).

Game farming in South Africa consists of three sub-sectors, namely: wildlife ranching (breeding and live capture and sale), wildlife activities (game viewing, trophy hunting and biltong hunting) and wildlife products (game meat products, skins and hides as well as other products) (Munzhedzi, 2018). At present, the game meat production sector is still largely undeveloped in comparison to the other sectors. This is due to an unestablished formal market that is subjected to irregular supply (Radder & le Roux, 2005). However, the potential exists for farmers to fill this gap in the local market. Once this market is better established, the export potential could also increase.

Impala are a popular species among game farmers due to its high fecundity rate, fast growth and early maturation rates, wide distribution and relative abundance (Bourgarel *et al*., 2002; Hoffman, Kritzinger, & Ferreira, 2005). A male to female ratio of 1:10 has been suggested for impala populations to ensure optimal breeding without adversely affecting fecundity rates. This can be achieved through culling excess males and all females older than three years after they have weaned their young (Fairall, 1985). Fairall (1983) has suggested annual cropping rates between 22% and 30% depending on the level of predation on the farm. The impala is thus an ideal species for continuous cropping regimes.

However, for game to be considered a viable alternative to domestic livestock, more information needs to be obtained regarding the yield and carcass composition of various game species. Despite the popularity of impala for meat production, very little information is available on the influence of age and sex on yield and carcass composition. The aim of this study is thus to produce baseline data on impala yield, which could assist farmers in selecting the ideal age at which to cull their animals.

3.2 MATERIALS AND METHODS

3.2.1 Animals and study location

A total of 32 semi-extensive farmed impala (*Aepyceros melampus*) were selected, comprising of 24 rams and eight ewes, and were part of the annual culling operation on the farm. Ethical approval was obtained (ACU-2018-6598) from the University of Stellenbosch's Animal Ethics Committee. The rams were divided into three age groups: 18-, 30- and 42-months-old. Age was determined by horn shape as well as from precise records that were kept due to the intensive breeding programs practised on the farm. The female animals were all 30-months-old. Each group contained eight animals. The impala were kept in separate camps ranging from 80 ha to over 2000 ha according to age and sex on the ranch.

All animals were located on Romaco Ranch (S24'' 26' 43.73" E28" 31' 25.86"), situated in the Limpopo province on the outskirts of Modimolle and Mookgophong, South Africa. The Limpopo province falls into the Savanna biome which has an average elevation of 750 - 1400 m and receives an annual rainfall of between 350 mm and 600 mm. The ranch is situated in the Waterberg Mountain valley. This mountainous area contains grassland plains, trees (especially *Faurea saligna* and *Protea caffra* trees) and tall shrubs (Rutherford, Mucina, & Powrie, 2006).

3.2.2 Culling and dressing

Animals were culled according to age group and sex during the day from a helicopter. A shotgun was used to deliver head and high neck shots. Headshots are considered most ideal, as they result in the least carcass damage and also prevent contamination with blood and intestinal fluids (McCrindle *et al*., 2013; Van Schalkwyk & Hoffman, 2016). The time of the shot and any additional information regarding the shooting were recorded in the field. During the operation, backup vehicles were stationed in the field to exsanguinate (drain the blood by cutting the jugular vein and carotid arteries) and collect animals after they had been shot. The animals were then loaded and transported to the registered abattoir (Certificate number 2/4G) on the farm for further processing.

Once the animals arrived at the abattoir, the dead weight was recorded. Evisceration and removal of the heads, hooves and skins were done according to the procedure described by Van Schalkwyk and Hoffman (2016). The heads, hooves and skins of each animal were weighed individually. Internal organs and gastrointestinal tracts were removed and weighed individually. In rams, the testes and penises were removed and the testes' weights and circumferences recorded. For each ewe, the udder was removed and weighed. After dressing, the carcasses were kept chilled at 4˚C for 24 hours to undergo rigor mortis.

Impala rams are bred for trophy hunting and selection is based on horn length. All 24 rams' horns were measured from the base of the horn, following the natural curve of the horn, towards the tip of both the left and right horn as indicated in Figure 3.1, measurement B. The distance between the tips were also measured as indicated by measurement A.

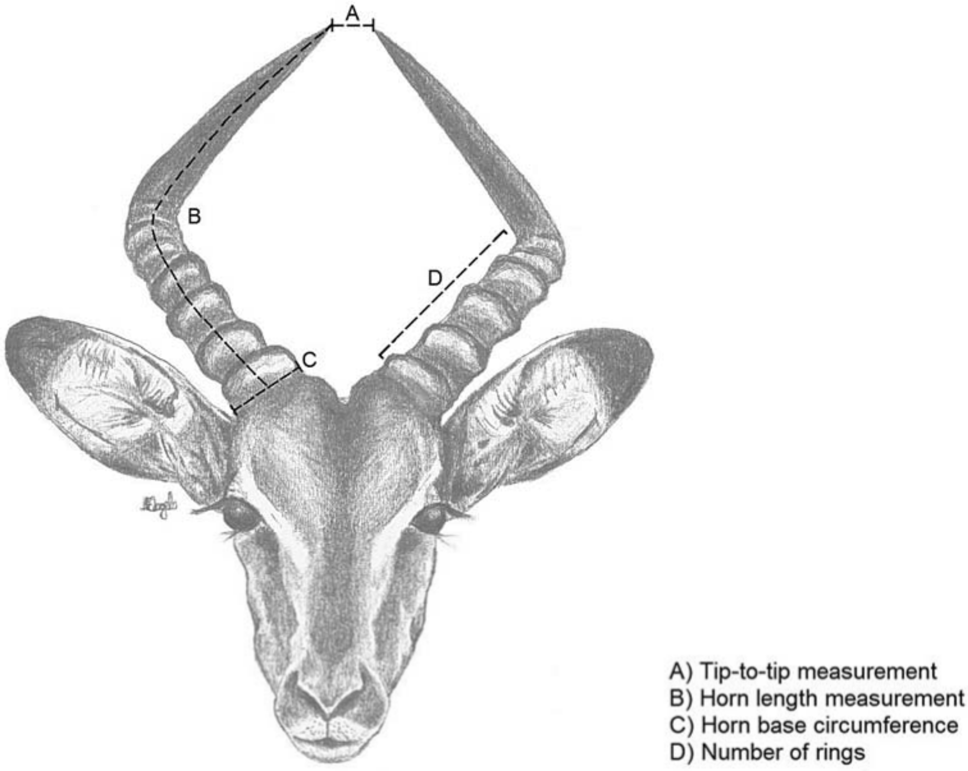

Figure 3.1. Illustration of an 18-month-old male impala and its horn measurements (Engels, 2019).

3.2.3 Sample preparation

. The following muscles were removed from the cold carcass: the *infraspinatus* (IS), *supraspinatus* (SS), *longissimus thoracis et lumborum* (LTL), *biceps femoris* (BF), *semimembranosus* (SM), *semitendinosus* (ST) as well as the fillet (*psoas major* and *p. minor*). The neck was removed at the juncture between the last cervical and first thoracic vertebrae and weighed individually. Both the left- and right-side muscles were removed from the carcasses and weighed. Kidney and caul fat, mainly found in mature animals, were removed and weighed.

3.2.4 Statistical analysis

A completely randomised design was used for both the age and sex data. For the age section, age was the main effect, sex the fixed effect and animal the experimental unit. For the sex section, sex was the main effect, age the fixed effect and animal the experimental unit. The age comparison included data from 24 impala rams divided into 3 age groups of 8 animals per group. The sex comparison included data from 8 rams and 8 same-aged ewes. Data was analysed with Statistica version 13.4's (2018). A variance estimation and precision model was used. The General Linear Models procedure was used to perform a univariate analysis of variance (ANOVA). A Shapiro-Wilk test was performed on the standardised residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). If a significant deviation from normality was observed, such as when the standardised residual for an observation deviated with more than three standard deviations from the model value, outliers were evaluated and where applicable, removed. To compare the means (for the age data), a Fisher's t-least significant difference was calculated at a significance level of 5% (Ott, 1998).

3.3 RESULTS

This study aims to determine the meat production potential of impala rams of different age groups as well as the effect of sex on meat production in South Africa. With limited information on this topic available in previous literature, this study aims to provide baseline data on the carcass characteristics and yields as influenced by age and sex. Romaco Ranch follows strict breeding programs and due to the nature of the business records are well maintained. This made accurate age prediction possible for each group.

3.3.1 Carcass yield

Table 3.1 represents the influence of different ages on the meat production potential of impala as well as the influence of sex on carcass yield of 30-month-old rams and ewes

Table 3.1 Least square mean carcass yield (± standard deviation) and *p*-values for different age groups and sexes of impala

Carcass yields	**Age (months)**				**Age**	***Sex**
	42; M	**30; M***	**18; M**	**30; F***	***p*-value**	***p*-value**
Dead weight (kg)	**58.3^a ± 5.99**	**48.4^b ± 2.66**	**34.8^c ± 4.28**	**41.1 ± 3.19**	**<0.01**	**<0.01**
Warm carcass weight (kg)	**34.1^a ± 4.025**	**28.3^b ± 1.52**	**20.2^c ± 2.93**	**23.5 ± 2.2**	**<0.01**	**<0.01**
Dressing %#	58.3 ± 1.77	58.5 ± 0.62	57.9 ± 1.36	57.2 ± 2.12	0.66	0.13

Dressing % calculated by dividing the warm carcass weight by the dead, undressed weight

*Sex comparison between 30-month-old ram and 30-month-old ewes.

^{abc}Means in the same row with different superscripts differ significantly (p < 0.05)

Age had a significant effect on the dead weight and carcass weight of impala rams (p <0.01). In both instances, the 42-month-old rams had the highest weight, followed by the 30-month and lastly the 18-month-old rams. No significant differences were observed between the dressing percentages of the different age groups. Sex significantly influenced the dead weight as well as the warm carcass weight between the rams and ewes. Rams had heavier dead and carcass weights in comparison to the ewes (Table 3.1). No differences were observed between the dressing percentages for sex (p = 0.13).

3.3.1.2 Economics of scale

When a fixed area (in this example, an area that can maintain 100 impala) and time (one year) is taken into consideration the production system used will largely influence the annual meat yield. Ranchers are of the opinion that they are able to predict the horn growth potential of 18-month old rams with an acceptable level of accuracy and thus rams that do not show potential can be culled. For the three age groups used in this study the following management scenarios are presented for illustration of potential meat yield:

1. An all-in all-out system. After selecting animals for trophy and breeding purposes the surplus 18-month-old rams will be culled and replaced at the start of the following season.
2. Keep for an additional 1 year. Rams will be kept for an additional one year until they are 30-months old. The herd will thus contain half 30-month-old and half 18-month old rams at the point of culling. 18-month-old animals will serve as replacement of the 30-month-old culled rams.
3. Keep for an additional 2 years. Rams will be kept for an additional two years until they are 42-months old. The herd will thus contain a third 42-month-old, a third 30-month old and a third 18-month-old rams at the point of culling of the 42-month-old rams. 30-month and 18-month-old animals will serve as a replacement for the upcoming years.

Table 3.2 depicts the calculated annual meat yield that will be obtained for a 100-animal herd when a 2% mortality is taken into account.

Table 3.2 The influence of production system on annual meat yield

Production system	[a] **Replacement animals 18-months-old**	**Replacement animals 30-months-old**	[b]**Animals lost due to mortality**	**Culled animals**	***Warm carcass weight** (kg)	**#Meat yield per annum** (kg)
All-in-all-out	0	0	2	98	20	1960 kg
Keep for one year	52	0	4	48	28	1344 kg
Keep for two years	37	24	6	32	34	1088 kg

[a] This number includes the additional animals to make up for the mortalities experienced in the previous year

[b] This is the cumulative number over the whole production period

* Warm carcass weight of each age group as depicted in Table 3.1

[#] Meat yield calculated by multiplying the number of culled animals with the mean carcass weight

Although the calculation of meat yield per fixed surface area per time unit depicted in Table 3.2 is of the most basic form, it is clear that the highest meat yield per annum will be obtained through the All-in all-out system where 18-month-old rams are slaughtered and replaced at the start of the following season. This higher yield of younger animals is correlated to the sigmoidal growth curve of impala where between 18-months and 30-months of age, the rams have reached sexual maturity (Brooks, 1978; Hanks *et al.,* 1976) and their growth rates have started plateauing. It is a common misconception amongst numerous farmers that older animals, being heavier will deliver more meat, which might be true per carcass but not when calculated per surface area per time unit.

3.3.2 Offal yield

The offal yields for the impala are presented in Table 3.2. The proportional weights (in percentage) were included to provide a better understanding of the proportional distribution of the impala body as influenced by age and sex. Organs form a large part of the traditional South African diet (Erasmus & Hoffman, 2017). The majority of game farms donate the organs and gastrointestinal tracts to their farm labourers or to local school feeding programs (McCrindle *et al*., 2013). If marketed correctly, offal can serve as an additional source of income to the industry. Further research is however needed to establish a marketing and supply chain that links producers and the end consumer (McCrindle *et al*., 2013).

There were significant differences observed between the weights of the red offal (heart, lungs, liver and kidney) within different age groups (Table 3.3): the 42-month-old rams' hearts and lungs were heavier than that of the 18-month-old rams, but not that of the 30-month-old rams. The 42-month-old rams' liver and kidney, however, were the heaviest compared to the other two age groups. When considering the proportional differences, only the heart and lungs showed a significant difference; both the heart and lungs made up a larger proportion of the dead weight of the 18-month-old animals than in the older animals. The testes within the different age groups showed significant differences both in terms of weight and proportional contribution. The heaviest weight was recorded for the 42-month-old rams, whereas the proportional contribution was found to be similar for both 30-month-old and 42-month-old rams.

Male impala had significantly heavier heads than ewes (Table 3.3). The head, for rams, also made up a larger proportion of the dead weight. The presence of horns in rams (impala ewes are hornless) would contribute to the heavier weight. The ewes had an average udder weight of 0.52 kg. This could also contribute towards a large proportion of the female dead weight. The heavy udder weight is a result of five out of the eight 30-month-old ewes being in lactation.

Table 3.3 Least square means (± standard deviation) of offal contribution (kg and %) of impala as influenced by age and sex.

Offal yield		Age (months)				Age *p*-value	*Sex *p*-value
		42; M	*30; M	18; M	*30; F		
Dead weight	kg	**58.3[a] ± 5.99**	**48.4 [b] ± 2.66**	**34.8[c] ± 4.28**	**41.1 ± 3.19**	**<0.01**	**<0.01**
Head[#2]	kg	**3.7[a] ± 0.70**	**3.2[b] ± 0.13**	**2.3[c] ± 0.20**	**2.0 ± 0.11**	**<0.01**	**<0.01**
	%[#1]	6.3 ± 0.70	6.5 ± 0.17	**6.7 ± 0.40**	**4.9 ± 0.22**	0.34	**<0.01**
Legs	kg	**1.3[a] ± 0.12**	**1.3[a] ± 0.083**	**1.09[b] ± 0.12**	**1.09 ± 0.079**	**<0.01**	**<0.01**
	%	**2.2[c] ± 0.12**	**2.6[b] ± 0.16**	**3.1[a] ± 0.079**	**2.7 ± 0.20**	**<0.01**	0.63
Skin	kg	**3.7[a] ± 0.52**	**2.8[b] ± 0.30**	**1.8[c] ± 0.31**	**2.1 ± 0.23**	**<0.01**	**<0.01**
	%	**6.4[a] ± 0.47**	**5.9[b] ± 0.50**	**5.2[c] ± 0.30**	**5.2 ± 0.45**	**<0.01**	**0.02**
Heart	kg	**0.3[a] ± 0.049**	**0.3[ab] ± 0.018**	**0.3[b] ± 0.045**	0.3 ± 0.031	**0.01**	0.26
	%	**0.6[b] ± 0.066**	**0.6[b] ± 0.046**	**0.8[a] ± 0.11**	**0.7 ± 0.69**	**<0.01**	**0.04**
Lungs	kg	**0.7[a] ± 0.11**	**0.7[ab] ± 0.12**	**0.6[b] ± 0.12**	0.6 ± 0.089	**0.04**	0.24
	%	**1.2[b] ± 0.20**	**1.4[b] ± 0.23**	**1.6[a] ± 0.18**	1.4 ± 0.18	**<0.01**	0.42
Liver	kg	**1.0[a] ± 0.21**	**0.7[b] ± 0.049**	**0.6[c] ± 0.065**	**0.6 ± 0.054**	**<0.01**	**<0.01**
	%	1.7 ± 0.26	1.5 ± 0.11	1.6 ± 0.096	1.6 ± 0.079	0.12	0.50
Kidney	kg	**0.2[a] ± 0.038**	**0.1[b] ± 0.015**	**0.1[c] ± 0.0088**	0.1 ± 0.017	**<0.01**	0.09
	%	0.3 ± 0.053	0.3 ± 0.027	0.3 ± 0.014	0.3 ± 0.042	0.95	0.42
Spleen	kg	0.2 ± 0.048	0.2 ± 0.037	**0.2 ± 0.041**	**0.1 ± 0.044**	0.96	**0.01**
	%	**0.3[c] ± 0.054**	**0.4[b] ± 0.067**	**0.6[a] ± 0.095**	0.3 ± 0.096	**<0.01**	0.11
GIT[#3]	kg	**11.0[a] ± 1.50**	**9.5[b] ± 0.68**	**6.9[c] ± 0.60**	9.6 ± 1.02	**<0.01**	0.73
	%	18.9 ± 2.64	19.6 ± 0.46	**19.8 ± 1.35**	**23.5 ± 2.09**	0.52	**<0.01**
Penis	kg	**0.04[a] ± 0.0087**	**0.04[a] ± 0.0041**	**0.02[b] ± 0.0092**		**<0.01**	
	%	0.07 ± 0.012	0.07 ± 0.0087	0.06 ± 0.019		0.06	
Testes	kg	**0.13[a] ± 0.023**	**0.09[b] ± 0.014**	**0.02[c] ± 0.012**		**<0.01**	
	%	**0.2[a] ± 0.038**	**0.2[a] ± 0.022**	**0.07[b] ± 0.022**		**<0.01**	
Total organs	kg	**14.7[a] ± 2.57**	**11.7[b] ± 0.84**	**9.1[c] ± 1.16**	11.7 ± 1.05	**<0.01**	0.94
	%	23.8 ± 2.67	24.2 ± 0.69	**25.3 ± 1.19**	**28.5 ± 2.35**	0.23	**<0.01**

[#1] Variable %= Contribution towards dead weight, [#2]Head= includes horns & tongue, [#3]GIT = Gastrointestinal tract, includes stomach & intestines.

M= Male, F = female

*Sex comparison between 30-moth-old male and 30-month-old female animals.

abc Means in the same row with different superscripts differ significantly ($p < 0.05$)

3.3.3 Muscle yield

Meat yield is considered the most important factor for any meat production enterprise. Eight muscles were thus analysed to assess the influence of age and sex on their yield (Table 3.4).

Table 3.4 Least square means (± standard deviation) of muscle yield of impala as influenced by age and sex.

Muscle yield		Age (months)				Age *p*-value	Sex* *p*-value
		42 M	30 M*	18 M	30 F*		
Carcass weight	kg	**$34.05^{a} \pm 4.02$**	**$28.3^{b} \pm 1.52$**	**$20.2^{c} \pm 2.93$**	**23.5 ± 2.2**	**<0.01**	**<0.01**
LTL[1]	kg	**$1.3^{a} \pm 0.12$**	**$1.1^{b} \pm 0.10$**	**$0.8^{c} \pm 0.11$**	1.0 ± 0.079	**<0.01**	0.09
	%[#1]	**$3.8^{b} \pm 0.16$**	**$3.9^{ab} \pm 0.29$**	**$4.07^{a} \pm 0.16$**	**4.4 ± 0.26**	**0.04**	**<0.01**
BF[2]	kg	**$0.9^{a} \pm 0.076$**	**$0.8^{a} \pm 0.05$**	**$0.6^{b} \pm 0.093$**	**0.7 ± 0.054**	**<0.01**	**0.02**
	%	**$2.5^{b} \pm 0.28$**	**$2.9^{a} \pm 0.19$**	**$2.9^{a} \pm 0.18$**	**3.2 ± 0.17**	**<0.01**	**<0.01**
SM[3]	kg	**$1.2^{a} \pm 0.11$**	**$1.0^{b} \pm 0.07$**	**$0.8^{c} \pm 0.099$**	**0.9 ± 0.06**	**<0.01**	**<0.01**
	%	**$3.4^{c} \pm 0.26$**	**$3.6^{b} \pm 0.15$**	**$4.0^{a} \pm 0.14$**	**4.0 ± 0.25**	**<0.01**	**<0.01**
ST[4]	kg	**$0.3^{a} \pm 0.016$**	**$0.2^{b} \pm 0.01$**	**$0.2^{c} \pm 0.027$**	**0.2 ± 0.014**	**<0.01**	**<0.01**
	%	**$0.8^{b} \pm 0.06$**	**$0.8^{a} \pm 0.048$**	**$0.8^{a} \pm 0.053$**	0.9 ± 0.06	**<0.01**	0.27
IS[5]	kg	**$0.3^{a} \pm 0.038$**	**$0.2^{b} \pm 0.044$**	**$0.2^{c} \pm 0.067$**	**0.2 ± 0.032**	**<0.01**	**0.02**
	%	0.9 ± 0.081	0.9 ± 0.14	0.9 ± 0.075	0.9 ± 0.074	0.48	0.53
SS[6]	kg	**$0.2^{a} \pm 0.027$**	**$0.2^{b} \pm 0.02$**	**$0.1^{c} \pm 0.038$**	**0.2 ± 0.014**	**<0.01**	**<0.01**
	%	**$0.6^{b} \pm 0.043$**	**$0.7^{ab} \pm 0.084$**	**$0.7^{a} \pm 0.035$**	0.6 ± 0.033	**0.04**	0.46
Fillet	kg	**$0.2^{a} \pm 0.021$**	**$0.2^{a} \pm 0.017$**	**$0.1^{b} \pm 0.019$**	**0.2 ± 0.014**	**<0.01**	**0.01**
	%	0.6 ± 0.083	**0.6 ± 0.06**	0.6 ± 0.05	**0.7 ± 0.081**	0.06	**0.01**
Neck	kg	**$2.4^{a} \pm 0.53$**	**$1.6^{b} \pm 0.18$**	**$1.1^{c} \pm 0.16$**	**1.1 ± 0.09**	**<0.01**	**<0.01**
	%	**$6.7^{a} \pm 1.24$**	**$5.8^{ab} \pm 0.78$**	**$5.4^{b} \pm 0.33$**	**4.7 ± 0.34**	**0.02**	**<0.01**

[#1] Variable %= Contribution towards carcass weight

*Sex comparison between 30-month-old male and 30-month-old female animals

Abreviation:[1]LTL = Longissimus thoracis et lumborum, [2]BF= biceps femoris, [3]SM = semimembranosus, [4]ST = semitendinosus, [5]IS = infraspinatus, [6]SS = supraspinatus.

abcMeans in the same row with different superscripts differ significantly ($p < 0.05$)

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There was a notable increase in weight with age for all eight selected muscles. The IS and fillet, however, did not show a significant difference in the proportion that they contribute towards the dead weight. All the muscle weights, except for the LTL, were significantly heavier in the rams. A large difference was observed in the neck weights recorded for the rams and ewes with the former having heavier necks

3.3.4 Horn measurements

As seen in Table 3.4, a significant difference was observed in horn length between the different aged rams. There was no difference between the 30- and 42-month-old rams, but a significant difference was observed between the 30- and 42-month-old rams and the 18-month-old rams

Table 3.5 Least square mean horn measurements (cm) (±standard deviation) of impala rams as influenced by age.

Horn Measurements	Age (months)			*p*-value
	42	30	18	
Total length	**47.9^{a} ± 2.57**	**46.1^{a} ± 2.73**	**31.9^{b} ± 3.81**	**<0.01**
Tip to tip	12.01 ± 3.73	7.9 ± 3.10	6.9 ± 6.06	0.07

^{abc}Means in the same row with different superscripts differ significantly ($p < 0.05$)

3.4 DISCUSSION

This study aimed to evaluate the meat production potential of impala as influenced by age and sex. There was a significant difference observed between the mean dead weights of the respective age groups (Table 3.1). Of the animals, the 42-month-old rams had the heaviest mean dead weight (58.3 ± 5.99 kg) and the 18-month-olds were the lightest (34.8 ± 4.28 kg). The mean dead weight of the 18-month-old rams (34.8 ± 4.28 kg) corresponds with the 33.0 ± 3.50 kg for 18-month-old rams harvested on Mara Research station, in the same region as that of the present experiment (Hoffman, Kritzinger and Ferreira, 2005). Engels (2019), however, found a slightly higher mean dead weight of 36.4 ± 1.30 kg for semi-extensive reared rams and an even higher mean dead weight for extensive rams (46.5 ± 1.12 kg) ranging between 15 and 18 months of age. The observed differences could be due to variation in the veld quality or varying ages within the sub-adult group of the different production systems analysed by Engels (2019). The mean dead weight of the 18-month-old rams was however higher than that reported by Anderson (1982), who observed a mean dead weight of 28.58 ± 3.01 kg for 18-month-old rams harvested near Empangeni, South Africa.

The 30-month-old rams' dead weight (48.4 ± 2.66 kg) corresponded with the adult weights observed by Anderson (1982) and Fairall (1983) of 44.2 ± 2.16 kg and 49.4 kg, respectively. Due to inconsistencies in what is considered adult age, it is impossible to accurately compare these values. Hoffman, Kritzinger and Ferreira (2005) found that male 30-month-old impala had a mean dead weight of 46.38 ± 0.39 kg, which aligns with the current findings (Table 3.1). Hoffman *et al.,* (2009) describe a mature or adult-age impala as one that has attained full adult dentition. For a male impala, this is estimated to occur after 30 months of age (Roettcher & Hofmann, 1970). Hoffman *et al.,* (2009) found that adult male impala had a mean dead weight of 58.21 ± 8.30 kg. This corresponds with the 42-month-old impala rams (Table 3.1), although large variation could occur within the above-mentioned adult classification, making accurate assumptions impossible. Hoffman, Kritzinger and Ferreira (2005) found that the mean dead weight of 42-month-old impala rams was 58.28 ± 3.74 kg. This largely coincides with the current finding of 58.3 ± 5.99 kg.

Warm carcass weight also showed a significant difference following the same trend, with 42-month-old rams having the heaviest mean warm carcass weight (34.05 ± 4.025 kg) and 18-month-old rams having the lightest mean warm carcass weight (20.2 ± 2.93 kg). However, the dressing percentage showed no significant difference between the age groups. Hoffman, Kritzinger and Ferreira (2005) recorded a slightly lighter carcass weight (18.83 ± 2.36 kg) and dressing percentage (56.99 ± 1.19 %) than that observed for the 18-month-old rams. However, Engels (2019) noted a similar warm carcass weight and dressing percentage (21.6 ± 0.82 kg and 57.4 ± 0.75 %, respectively) as those measured in the current findings (Table 3.1). The warm carcass weight (25.62 ± 4.64 kg) and dressing percentage (55.03 ± 2.48 %) observed by Hoffman, Kritzinger and Ferreira (2005) were, however, lower than those observed in the current findings. This could be due to several factors, including differences in season, time of culling as well as slaughtering procedures. Fairall (1983) too had a lower dressing percentage (56.9 %) for mature adult rams than was observed for both the 30-month-old and 42-month-old rams (Table 3.1). This could be attributed to the small sample size used by Fairall (1983) as well as the lower than usual rainfall that was experienced during his study which would have resulted in sub-optimal feeding. Despite the similar dead weights reported by Hoffman *et al.,* (2009) for mature adults rams, the carcass weight (37.89 ± 4.46 kg) and dressing percentage (60.9 ± 1.18 %) were higher than those recorded for the 42-month-old rams. However, this could be attributed to differences in slaughtering techniques, season and variation in gut fill; the latter is known to strongly influence dressing percentage.

There were significant differences between the dead weights and warm carcass weights of 30-month-old impala rams and ewes, with the rams being heavier. There was however no significant difference between the dressing percentage of rams and ewes. Hoffman, Kritzinger and Ferreira (2005) found similar trends for 30-month-old impala harvested at Mara Research Station and Musina Experimental Farm in Limpopo, South Africa. The Mara animals had a slightly heavier dead weight (55.50 ± 0.00 kg and 43.85 ± 2.69 kg) and carcass weights (33.84 ± 0.00 kg and 27.66 ± 1.54 kg) for male and female impala respectively, in comparison to the present study. This could be ascribed to the exceptionally good rainfall in the Mara area experienced the two seasons prior to their study ensuring sufficient nutrition whilst during the present study the ranch had been experiencing a prolonged drought.

Due to sexual dimorphism, it is expected to find slight differences in dressing percentages of male and female impala (Hoffman, Kritzinger, & Ferreira, 2005). However, this was not the case in the present study nor the Mara and Musina studies. The GIT made up a larger percentage of the total body weight of the females, but on the other hand, the horns of the rams contribute a large proportion to the rams' waste component. There was thus no difference in the contribution of the offal towards to total body weight, resulting in no significant differences in dressing percentage.

The rams had a moderate fat cover with a body condition score of between approximately 2 - 3 ± 0.5. The ewes had a lower fat score due to five out of the eight ewes being in lactation. The body condition score of the ewes varied between approximately 1 - 2 ± 0.5.

As seen in Table 3.3 an increase in age results in an increase in the weights of the red offal. When considering the proportional differences, only the heart and lungs showed a significant difference; both the heart and lungs made up a larger proportion of the dead weight of the 18-month-old animals than in the older animals. This could be because of the allometry of growth, which causes vital organs to develop before muscle, thus contributing a larger proportion to the weight in a younger animal. The heavier weight of the testes in 42-month-old rams could be attributed to them having reached full sexual maturity as well as the fact that they were harvested in April when the rams were already in rut (Furstenburg, 2016).

Regardless of age and sex, impala produce high-quality skins that are ideal for tanning (Oberem & Oberem, 2016). Presently, the cost of tanning impala skins varies between R437 - R510. Skins are however sold for between R550 - R700. With such a relatively small profit margin impala skin production will only be economically feasible if done on a large scale. A skin processing facility will thus be needed, requiring further input costs. The establishment of a fixed market will also be necessary to ensure the sustainability of a skin processing facility. This is an area that warrants further research.

All the muscles showed an increase in weight with age (Table 3.4). The proportional differences did however not differ with age for the IS and Fillet. This could be ascribed to the fact that both muscles are very small in size and that the changes in weight were not large enough to significantly change their proportional contribution. The significant difference between the neck weight of rams and ewes could be due to the rams having entered the rut and deposited fat in their necks (Furstenburg, 2016).

Horn measurements are an important factor to consider as breeding rams are selected based on their horn growth potential. Rams are usually selected at 18-months of age for either trophy breeding or meat production. A significant difference in horn length was observed between the age groups (Table 3.5). Anderson (1982) found similar measurements for 18-month-old and mature rams from Empangeni, South Africa. The horn growth of an impala is at its most active growth phase at approximately 18 months and reaches a maximum at 54 months (Spinage, 1971). No significant differences were noted between the length of the 30-month and 42-month-old rams. This could indicate that the horn growth started to reach a plateau indicating that adult age is reached at approximately 30-months of age.

3.5 CONCLUSION

This study has provided baseline data on the effect of animal age and sex on the meat and offal production potential of impala. It is clear from the above results that 42-month-old impala had the heaviest carcasses, produced the heaviest muscles and the highest offal yield. When different management scenarios are however taken into account the 18-month-old animals give the largest meat yield per surface area per time unit. This is due to carrying capacity limitations as well as the effect of mortality being more severe in older animals. Older animals have also already passed their point of maximum growth rate and the weight increase per year is less than what was achieved the previous year. This information could prove useful to farmers deciding on the ideal age at which to cull their animals. Further research on the effect of age on the meat-to-bone ratio will also provide valuable information regarding the meat production potential of impala.

Male 30-month-old impala produced heavier carcasses and heavier muscles than female animals. This study was however limited to only 30-month-old animals and further research is thus needed which evaluates the effect of sex over a wider range of ages. Ewes are typically kept for four lambing seasons where after culled. It is thus important to evaluate the meat quality of older animals that are used for meat production after they have passed the peak of their reproductive prime.

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CHAPTER 4

PHYSICAL MEAT QUALITY ATRIBUTES OF IMPALA (*Aepyceros melampus*) AS INFLUENCED BY AGE AND SEX

ABSTRACT

A total of 32 impala were harvested from the Mookgophong area in Limpopo, South Africa during an annual culling operation. The animals were grouped according to age and sex and consisted of 24 male and eight female animals. The physical meat quality characteristics were determined on six muscles for the different age and sex groups. Age had no effect on the cooking loss, drip loss, tenderness as well as the colour of the meat. Sex (of same aged animals) had a significant effect on some of the muscles analysed. The effect was visible in the lightness (L*) of the muscles; ewes showed lower L* values and thus darker meat. This could be due to the difference in pH between rams and ewes, the ewes had higher pH readings. Despite these slight differences, impala meat irrespective of age or sex has an inherently high quality that is ideal for fresh game meat production.

Keywords: age, impala, physical meat quality, sex

4.1 INTRODUCTION

A consumer's perception of game meat quality is influenced by various factors such as culture, education, income and previous experiences (Tomasevic *et a*l., 2018). These are all factors that are predetermined before the point of purchase, but are major factors that will influence a consumers buying behaviour (Issanchou, 1996). At the point of purchase, the consumer relies on visual cues to give an indication of potential quality. This includes colour, drip loss and the amount of visible fat. Factors such as tenderness, juiciness and flavour are however only experienced at the point of consumption and are the main factors that will determine whether a consumer will buy a product again (Troy & Kerry, 2010). In central Europe, a survey performed in ten European countries found that consumers rated taste, overall quality (including texture and other physical attributes), and odour as the most important sensory characteristics as pertaining to game meat (Tomasevic *et al*., 2018).

It is thus important to determine the physical meat quality characteristics of game species to ensure consumer satisfaction and market competitiveness with traditional livestock (Kohn *et al.,* 2015). Hoffman *et al*., (2005) found that South African consumers are not well informed regarding the positive attributes of game meat. They also noted that more needs to be done by producers and marketers of game meat to promote the product and to inform consumers of the various health and environmental benefits. In Poland, Kwiecińska and co-workers (2017) predicted factors that would increase the consumption of game meat and found that consumers are likely to increase their consumption of game when quality and availability is improved.

Wiklund, Manley & Littlejohn (2004) concluded that the muscle glycogen levels of deer at slaughter has an influence on the physical meat quality with regards to surface colour, water-holding capacity, shelf-life and tenderness. Glycogen levels can be estimated by the ultimate pH (pH_u) value of meat ±24 hours post-mortem. Consumers associate meat surface colour with freshness and it thus plays a vital role in consumer acceptance of the product (Mancini & Hunt, 2005; Troy & Kerry, 2010). Meat colour is influenced by the chemical form and content of myoglobin in muscle. Myoglobin content is related to the function and level of activity of the muscles (Neethling *et al.,* 2017). Tenderness is the main factor influencing the eating experience and consumer acceptance of the product. Meat tenderness is influenced by various factors such as species, sex, age, stress and the rate of chilling (Troy & Kerry, 2010). Yet, little research has been reported that evaluates some of these factors in game meat, particularly as pertaining to impala.

Impala is a popular ungulate species amongst game farmers and make up 24.1% of animal numbers on game ranches (Taylor *et al*., 2016). Impala also have high reproductive rates and are adapted to a variety of habitats. All these factors make impala an ideal species for game meat production (Fairall, 1983; Furstenburg, 2016; Kritzinger, Hoffman, & Ferreira, 2003; Mason, 1976). With the intensive breeding of impala (mainly for coat colour with the black recessive gene being the most sought after variant) (Furstenburg, 2016) farming practices such as individual marking of animals has resulted in an expansion of selective culling of excess animals. This gives an ideal scenario to evaluate some of the factors that influence meat quality more accurately. Also, previous research on impala meat quality has focused mainly on the *longissimus thoracis et lumborum* (LTL) muscle as well as only between adult and sub-adult animals (Hoffman *et al.,* 2009). With this limitation in mind, the aim of this study is to investigate the influence of animal age and sex on the physical meat quality attributes of six impala muscles.

4.2 MATERIALS AND METHODS

4.2.1 Animals and study location

A total of 32 Impala (*Aepyceros melampus*) were used during this study. The animals were all sourced from Romaco Ranch (S24’’ 26’ 43.73” E28” 31’ 25.86”) located in the Limpopo province, South Africa. The animals were grouped according to age and sex. Rams were divided into three age groups of 18-months, 30-months and 42-months old, with eight animals per group. The ewes were all 30 months of age. The animals all formed part of the annual culling operation on the farm. Ethical clearance (ACU-2018-6598) was granted by the Stellenbosch University Animal Care and Use Committee prior to the initiation of field work.

See Materials and Methods of Chapter 3.2.1 for further detail.

4.2.2 Culling and dressing

The animals were culled according to their age group and sex. All the animals were culled through head or high neck shots. Headshots result in very little damage to the carcass and prevents contamination with blood and intestinal fluids (Van Schalkwyk & Hoffman, 2016). Culling took place during the day from a helicopter. Animals were exsanguinated in the field and transported to the registered abattoir (certificate number 2/4G) on-farm for further processing. The time of shot and any additional notes regarding the shooting were recorded in the field. When the animals arrived at the abattoir evisceration and dressing (removal of skin, head, feet, etc.) took place according to the procedure described by Van Schalkwyk & Hoffman, (2016). After dressing, the carcasses were stored in a 4˚C chiller for 24 hours to undergo rigor mortis.

4.2.3 Sample preparation

After the carcasses had cooled for ~24h the following muscles were removed from the left and right side of the carcass: the *infraspinatus* (IS), *supraspinatus* (SS), *longissimus thoracis et lumborum* (LTL), *biceps femoris* (BF), *semimembranosus* (SM) and *semitendinosus* (ST). All the muscles from the left side were retained for physical analysis.

4.2.4 Physical analysis

For the physical analysis all visible epimysium was removed from all the muscles and three 1.5 cm steaks were cut out from the middle of each muscle, perpendicularly to the muscle fibre.

4.2.4.1 Acidity (pH)

A calibrated Crison pH25 pH (Crison Instruments, Barcelona, Spain) meter with a glass electrode was used for all pH measurements. pH_u (ultimate pH) measurements were taken ~24h post-mortem from the centre of each muscle after they have been removed. The electrode was washed with distilled water in between each measurement and recalibrated after every 10 readings.

4.2.4.2 Colour

The meat surface colour was measured after one steak of each muscle was bloomed for 30 minutes before the same steak was used for the cooking and drip loss analyses. Colour measurements were taken with a calibrated Color-guide 45°/0° colorimeter (aperture size 8 mm; illuminant/observer of D65/10°) (Catalogue number 6801; BYK-Gardner GmbH, Gerestried, Germany) on five different areas on the surface of the cut meat. Calibration of the colorimeter was done after every 10 samples, using the standards provided (BYK-Gardner). The measurements were according to the CIE Lab colour system, that reports values as CIE L* (lightness), CIE a* (red-green spectrum) and CIE b* (blue-yellow spectrum). The CIE a* and CIE b* values were used to calculate the chroma (saturation/colour intensity) and hue-angle (colour definition) values (American Meat Science Association, 2012) according to the following equations:

$$\text{Hue- angle } (^\circ) = \tan^{-1}\left(\frac{b^*}{a^*}\right)$$

$$\text{Chroma } (C^*) = \sqrt{(a^*)^2 + (b^*)^2}$$

4.2.4.3 Water holding capacity (WHC*)*

The water holding capacity of the steaks was determined by measuring drip loss of fresh meat samples as well as cooking loss of cooked meat as described by Honikel (1998). For drip loss, the steaks were weighed to determine the initial weights. The steaks were then suspended in an inflated plastic bag, without touching the sides for 24 hours inside a 4˚C chiller. After 24 hours the samples were removed and blotted dry with absorbent paper where after the final weights were recorded. The drip loss of each sample was expressed as a percentage of the initial weight of the sample (Honikel, 1998). Cooking loss was determined by taking the initial weight of the cut steaks and then submerging them inside clear plastic bags, in a heated water bath (80˚C) for 60 minutes. After the samples were cooked, they were removed, and all excess water drained. The samples were allowed to cool overnight in the chiller (4˚C) were after they were blotted dry and the final weight recorded. The cooking loss percentage was calculated by determining the difference between the raw and cooked mass and expressing it as a percentage of the original mass.

4.2.4.4 Warner-Bratzler shear force (WBSF)

The cooked meat samples were used to measure tenderness by determining the Warner-Bratzler shear force (WBSF) of each sample after the cooking loss was determined. Six cylindrical cores, 1.27 cm in diameter, were bored from the centre of the cooked steaks. Any visible collagen was avoided. The cylindrical cores were sheared perpendicularly to the fibre's longitudinal axis with a Warner Bratzler blade (Universal Testing Machine, Model 4444, Apollo Scientific, South Africa), 1.2 mm thick with a triangular opening, 13 mm at the widest point and 15 mm high at a speed of 3.33 mm/s. The blade was fitted to an electrical scale that measures the maximum force required to shear through the sample. Measurements were recorded in kg per 1.27 cm Φ diameter. The average between the six WBSF readings were calculated to determine the tenderness of each muscle, with lower values indicating tender meat (Honikel, 1998). The averages were converted to Newton (N) to maintain consistency throughout the study as well as to allow for comparison with other findings. The following equation were used to convert kg/1.27cm Φ diameter to Newton (N):

$$\text{Shear force (N)} = \text{kg per } 1.27 \text{ cm } \Phi * 9.81 / \text{Area}$$

$$\text{Where area} = \pi \, (1.27/2)^2$$

4.2.4.5 Myoglobin analysis

The myoglobin concentration was determined according to Tang *et al*., (2004). Briefly, a 10 g sample was homogenised (P-8; Kinematica, Littau, Switzerland) in 100 ml cold 40 mM potassium phosphate buffer that was adjusted to a pH of 6.8. The homogenised sample was allowed to extract at 4°C for 1 hour. After extraction, the sample was centrifuged (Sigma 2-16 K, Wirsam Scientific, Cape Town, South Africa) for 30 minutes at 4,000 rpm at 4°C. The absorbance of the supernatant was measured with a spectrometer (Spectrostar Nano, BMG Labtech, Ortenberg, Germany) at 525 nm (A_{525}). The total myoglobin concentration was calculated as follows:

Total myoglobin concentration (mg/g meat) = (A_{525} / 7.6) × 17 × 11

Where:

7.6 = Millimolar extraction coefficient for myoglobin at 525 nm

17 = Average myoglobin molecular mass

11 = Dilution factor

4.2.5 Statistical analysis

A completely randomised design was used for both the age and sex data. Data was analysed with Statistica version 13.4 (2018) A variance estimation and precision model was used. A mixed model repeated measures procedure was used to perform an analysis of variance (ANOVA). A Shapiro-Wilk test was performed on the standardised residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). If a significant deviation from normality was observed, such when the standardised residual for an observation deviated with more than three standard deviations from the model value, outliers were evaluated and where applicable, removed. To compare the means (for the three ages), a Fisher's t-least significant difference was calculated at a 5% significance level (Ott, 1998).

4.3 RESULTS

4.3.1 pH

The age of the rams did not influence the pH_u of the LTL (p = 0.83) and SM (p = 0.08) muscle although age had a significant effect on the BF, ST, IS and SS muscle with the 18-month-old rams having a higher pH_u (for all of these four muscles) than both the 30- and 42-month-old rams (Table 4.1).

Sex had no effect on the pH_u of the LTL (p = 0.42) and BF (p = 0.09) muscles (Table 4.1). The SM, ST, IS and SS showed a significantly higher pH_u for the ewes in comparison to the rams.

Table 4.1 Least square means of pH (± standard deviation) of impala meat as influenced by age and sex.

$pH_{(u)}$	Age (months)				Age	*Sex
	42; M	***30; M**	**18; M**	***30; F**	***p*-value**	***p*-value**
LTL	5.6 ± 0.21	5.6 ± 0.22	5.6 ± 0.075	5.7 ± 0.27	0.83	0.42
BF	**5.5^b ± 0.12**	**5.5^b ± 0.12**	**5.7^a ± 0.079**	5.6 ± 0.047	**<0.01**	0.09
SM	5.6 ± 0.076	**5.6 ± 0.14**	5.7 ± 0.10	**5.8 ± 0.12**	0.08	**0.03**
ST	**5.5^b ± 0.12**	**5.5^b ± 0.11**	**5.6^a ± 0.069**	**5.6 ± 0.47**	**0.04**	**0.02**
IS	**5.8^b ± 0.12**	**5.7^b ± 0.097**	**5.9^a ± 0.057**	**5.9 ± 0.01**	**<0.01**	**<0.01**
SS	**5.7^b ± 0.12**	**5.8^{ab} ± 0.091**	**5.9^a ± 0.056**	**5.9 ± 0.064**	**0.01**	**0.03**

*Sex comparison between 30-month-old male and 30-month-old female animals

^{a,b,c} Means with different superscripts in the same row differ significantly from each other ($p \leq 0.05$).

4.3.2 Water holding capacity.

Apart from the cooking loss percentage of the ST muscle, there was no significant difference between the water holding capacity of the six muscles of the different aged impala rams (Table 4.2). For the ST muscle, the 42-month-old rams (35.4 ± 2.062%) had the highest cooking loss and the 18-month-old rams (32.1 ± 0.45%) the lowest.

All the muscles, apart from the BF (p = 0.04), showed no differences in drip loss percentage between rams and ewes. For the BF muscle, the ewes showed a slightly higher drip loss percentage than the rams. The LTL, SM, IS and SS muscles showed no difference in cooking loss percentage between rams and ewes (Table 4.2). The BF (p <0.01) and ST (p <0.01) however, showed a significant difference with the rams having a higher cooking loss than the ewes.

Table 4.2 Least square means of drip and cooking loss percentage (± standard deviation) of impala meat as influenced by age and sex.

		Age (months)				Age	*Sex
		42; M	***30; M**	**18; M**	***30; F**	***p*-value**	***p*-value**
Drip loss %	LTL	1.5 ± 0.51	1.6 ± 0.40	1.5 ± 0.47	1.5 ± 0.20	0.88	0.61
	BF	1.3 ± 0.18	**1.1 ± 0.16**	1.3 ± 0.99	**1.3 ± 0.22**	0.85	**0.04**
	SM	1.9 ± 0.69	2.0 ± 0.68	1.6 ± 0.27	1.7 ± 0.31	0.33	0.23
	ST	1.1 ± 0.11	1.0 ± 0.21	1.2 ± 0.48	1.1 ± 0.16	0.76	0.28
	IS	1.1 ± 0.15	1.3 ± 0.34	1.4 ± 0.52	1.3 ± 0.17	0.31	0.70
	SS	1.1 ± 0.11	1.1 ± 0.16	1.2 ± 0.32	1.3 ± 0.22	0.64	0.06
Cooking loss %	LTL	35.4 ± 2.32	35.9 ± 1.6	34.5 ± 1.14	34.9 ± 1.75	0.27	0.23
	BF	37.8 ± 1.99	**37.5 ± 2.14**	35.7 ± 2.16	**34.1 ± 1.74**	0.12	**<0.01**
	SM	38.6 ± 1.78	38.5 ± 1.88	39.3 ± 0.96	38.6 ± 1.48	0.55	0.96
	ST	**35.4^{a} ± 2.06**	**33.8^{b} ± 1.22**	**32.1^{c} ± 0.45**	**31.0 ± 1.57**	**<0.01**	**<0.01**
	IS	34.4 ± 5.49	32.8 ± 2.14	30.3 ± 1.40	31.6 ± 0.98	0.09	0.18
	SS	38.0 ± 1.84	36.8 ± 3.13	35.5 ± 1.55	36.1 ± 1.85	0.12	0.56

*Sex comparison between 30-month-old male and 30-month-old female animals

^{a,b,c} Means with different superscripts in the same row differ significantly from each other ($p \leq 0.05$)

4.3.3 Shear force

Age had no effect on the shear force of any of the muscles analysed (Table 4.3). The BF muscle, had a higher shear force for the ewes (47.2 ± 10.45 N) than the rams (36.8 ± 7.21 N). For the ST muscle the ewes also had a higher shear force (23.3 ± 2.91 N) in comparison to the rams (18.6 ± 4.83 N).

Table 4.3 Least square means of shear force (± standard deviation) of impala meat as influenced by age and sex.

	Age (months)				Age	*Sex
Shear force (N)	**42; M**	***30; M**	**18; M**	***30; F**	***p*-value**	***p*-value**
LTL	36.1 ± 8.52	39.1 ± 10.70	34.2 ± 7.87	38.3 ± 10.25	0.34	0.94
BF	34.0 ± 5.41	**36.8 ± 7.21**	35.3 ± 6.97	**47.2 ± 10.45**	0.5	**<0.01**
SM	35.4 ± 9.94	41.2 ± 10.08	39.3 ± 9.59	44.9 ± 10.46	0.26	0.35
ST	27.4 ± 6.27	26.0 ± 3.60	28.1 ± 4.80	26.4 ± 4.75	0.37	0.69
IS	21.4 ± 3.75	**18.6 ± 4.83**	20.3 ± 4.16	**23.3 ± 2.91**	0.23	**<0.01**
SS	25.3 ± 5.80	23.2 ± 5.19	20.4 ± 6.63	22.7 ± 5.05	0.11	0.79

*Sex comparison between 30-month-old male and 30-month-old female animals

^{a,b,c} Means with different superscripts in the same row differ significantly from each other ($p \leq 0.05$).

4.3.4 Colour

As seen in Table 4.4, age had no effect on the lightness of the LTL, BF, SM and ST muscles. It did however affect the IS (p = 0.01) and SS muscle (p = 0.03).

Table 4.4 Least square means of colour measurements (± standard deviation) of impala meat as influenced by age and sex.

	Colour measurements	Age (months)				Age	*Sex
		42; M	*30; M	18; M	*30; F	p-value	p-value
L*	LTL	30.4 ± 1.48	**30.6 ± 1.76**	30.8 ± 1.80	**28.3 ± 1.55**	0.78	**<0.01**
	BF	32.5 ± 2.10	**33.6 ± 1.53**	32.0 ± 2.20	**29.8 ± 1.68**	0.19	**<0.01**
	SM	31.5 ± 2.04	**31.1 ± 1.49**	30.1 ± 1.81	**27.6 ± 1.49**	0.17	**<0.01**
	ST	36.3 ± 2.35	**37.5 ± 2.88**	36.1 ± 2.58	**31.5 ± 7.77**	0.38	**0.03**
	IS	**32.3^{b} ± 1.71**	**32.8^{b} ± 1.88**	**34.6^{a} ± 1.77**	31.6 ± 1.60	**0.01**	0.11
	SS	**33.0^{b} ± 1.89**	**34.1^{ab} ± 2.03**	**35.4^{a} ± 1.55**	**32.2 ± 1.42**	**0.03**	**0.03**
a*	LTL	11.7 ± 1.45	11.0 ± 1.65	10.6 ± 0.91	10.5 ± 1.28	0.22	0.32
	BF	12.0 ± 1.75	11.4 ± 1.17	10.7 ± 1.05	11.0 ± 1.75	0.1	0.4
	SM	12.0 ± 1.97	11.9 ± 1.54	11.2 ± 1.21	11.2 ± 1.15	0.39	0.28
	ST	12.3 ± 2.40	11.0 ± 2.16	11.4 ± 1.82	12.1 ± 1.65	0.32	0.08
	IS	13.3 ± 1.63	13.5 ± 1.09	12.9 ± 1.09	13.9 ± 1.13	0.55	0.19
	SS	13.1 ± 1.31	12.9 ± 1.08	12.8 ± 1.23	13.5 ± 1.37	0.75	0.16
b*	LTL	8.6 ± 1.31	**8.6 ± 1.47**	7.9 ± 1.10	**7.2 ± 0.97**	0.4	**0.01**
	BF	**9.4^{a} ± 1.33**	**9.3^{a} ± 1.05**	**8.1^{b} ± 0.93**	**8.0 ± 0.83**	**0.02**	**<0.01**
	SM	9.9 ± 1.54	**9.7 ± 1.29**	8.8 ± 0.10	**8.5 ± 0.91**	0.14	**0.03**
	ST	11.9 ± 1.19	11.5 ± 1.19	11.1 ± 0.67	11.2 ± 0.88	0.2	0.39
	IS	9.5 ± 1.55	9.8 ± 0.82	10.1 ± 0.91	9.7 ± 0.87	0.49	0.66
	SS	9.6 ± 1.17	9.9 ± 1.09	10.4 ± 0.98	9.9 ± 0.86	0.21	1
h^{ab}	LTL	**36.2^{b} ± 1.67**	**37.7 ^{a}± 1.78**	**36.8^{ab} ± 2.40**	**34.6 ± 3.14**	**0.05**	**0.03**
	BF	37.9 ± 3.38	39.17 ± 1.67	37.1 ± 2.42	36.2 ± 3.97	0.06	0.41
	SM	39.5 ± 3.91	39.2 ± 1.87	38.2 ± 2.09	37.3 ± 2.00	0.40	0.18
	ST	44.5 ± 5.86	46.7 ± 5.28	44.5 ± 4.80	42.8 ± 4.11	0.54	0.27
	IS	**35.4^{b} ± 2.80**	**36.2^{ab} ± 2.34**	**38.0^{a} ± 2.19**	**34.9 ± 1.81**	**0.03**	**<0.01**
	SS	**36.2^{b} ± 2.00**	**37.4^{ab} ± 2.18**	**39.0^{a} ± 2.41**	**35.8 ± 1.28**	**0.03**	**<0.01**
C*	LTL	14.6 ± 1.90	14.0 ± 2.17	13.2 ± 1.31	12.7 ± 1.45	0.31	0.27
	BF	15.3 ± 2.02	14.8 ± 1.51	13.5 ± 1.28	13.6 ± 1.63	0.06	0.66
	SM	15.6 ± 2.28	15.3 ± 1.94	14.3 ± 1.48	14.1 ± 1.38	0.23	0.76
	ST	17.2 ± 2.1	16.0 ± 2.00	16.0 ± 1.41	16.5 ± 1.45	0.21	0.27
	IS	16.3 ± 2.11	16.7 ± 1.19	16.4 ± 1.26	17.0 ± 1.32	0.84	0.16
	SS	16.3 ± 1.67	16.3 ± 1.40	16.5 ± 1.42	16.7 ± 1.36	0.84	0.68

*Sex comparison between 30-month-old male and 30-month-old female animals

^{a,b,c} Means with different superscripts in the same row differ significantly from each other ($p \leq 0.05$).

The 18-month-old rams' IS muscles were lighter than both the older age groups'. For the SS muscle, the 18-month-old rams had lighter muscles than the 42-month-old rams.

Age also had no effect on any of the a*, all the b* (apart from the BF muscle) and none of the C* values (Table 4.5). The 30-month-old rams had a higher h^{ab} value (p = 0.05) than the 42-month-old rams. For the IS and SS muscle the 18-month-old rams had a higher h^{ab} value (p = 0.03) in comparison to the 42-month-old rams.

Sex had an effect (p <0.01 / 0.03) on the L* values of all the muscles, apart from the IS muscle. In all the above-mentioned differences the ewes had lower L* values and thus darker meat than the rams as seen in Table 4.5. The rams had a higher b* value than the ewes for the LTL, BF and SM muscle. The h^{ab} was also higher in the rams for the LTL, IS and SS muscle.

4.3.5 Total myoglobin content

The influence of age and sex on the concentration of the total amount of myoglobin in the different muscles were determined (Table 5.3). Apart from the LTL muscle, age had no significant effect on the total myoglobin concentration; for the LTL muscle, the 42-month-old rams had a significantly higher (p = 0.01) myoglobin concentration than both the 30- and 18-month-old rams.

Table 4.5 Total myoglobin concentration (mg/g meat) of impala meat as influenced by age and sex. Values indicated as least square means (±standard deviation).

Total Mb (mg/g)	**Age (months)**				**Age**	***Sex**
	42; M	***30; M**	**18; M**	***30; F**	***p*-value**	***p*-value**
LTL	**9.7^{a} ± 1.29**	**8.2^{b} ± 0.56**	**8.4^{b} ± 0.77**	**10.4 ± 1.98**	**0.01**	**<0.01**
BF	8.5 ± 0.92	9.3 ± 2.61	8.8 ± 1.22	11.0 ± 2.18	0.66	0.17
SM	8.3 ± 1.25	**8.2 ± 1.38**	8.3 ± 0.92	**10.7 ± 1.44**	0.98	**<0.01**
ST	8.2 ± 1.17	7.7 ± 0.91	7.7 ± 0.72	8.3 ± 2.23	0.46	0.51
IS	10.2 ± 1.72	10.7 ± 3.57	8.7 ± 0.63	10.2 ± 1.57	0.22	0.72
SS	10.1 ± 1.68	10.2 ± 1.27	9.0 ± 0.87	11.6 ± 2.17	0.14	0.16

*Sex comparison between 30-month-old male and 30-month-old female animals

^{a,b,c} Means with different superscripts in the same row differ significantly from each other ($p \leq 0.05$).

Apart from the LTL and SM muscles, sex had no significant effect on the total myoglobin concentration. For the LTL and SM muscles, the female animals had a significantly higher (p <0.01) myoglobin concentration in comparison to the males.

4.4 DISCUSSION

This study aimed to quantify the effect of animal age and sex on the physical meat quality characteristics of impala. The pH of meat is an important quality characteristic as it influences the water holding capacity, tenderness, colour and shelf life (Lawrie & Ledward, 2006). Under normal circumstances, the pH of meat will drop from around 7.0 - 7.2 to a pH_u of 5.3 - 5.8. The extent of pH decline is due to the amount of glycogen present in the ante mortem muscle that can be converted to lactic acid during anaerobic glycolysis. The amount of glycogen present will amongst others, be influenced by environmental ante mortem stressors (Honikel, 2004a; Lawrie & Ledward, 2006). All the impala in this investigation were culled from a helicopter and although it was highly efficient, the impact of this culling method on impala meat quality is unknown. All the impala tended to scatter and attempted to hide under bushes during the culling operation. It was also noted that it is more the down-draft caused by the helicopter blades rather than the helicopter noise that caused the impala to flee. Nonetheless, all the impala were culled in this manner and it is assumed that the stress experienced was similar among all animals. The majority of the pH_u values measured lie within the normal range, with the exception of the IS and SS muscle of the 18-month-old rams and 30-month-old ewes (Table 4.1). The variation observed between the muscles are a result of varying ante mortem glycogen levels due to differences in the function and level of activity within these muscles (Honikel, 2004b). Age had no effect on the pH_u of the LTL and SM muscle (Table 4.1). The same was observed between adult and sub adult impala LTL muscles that were harvested in the same area as the present study (Hoffman *et al*., 2009). Male fallow deer also showed no difference in the LTL and SM muscles' pH_u between 18- and 30-month old animals (Volpelli *et al.,* 2003).

The female animals showed a higher pH_u for majority of the muscles apart from the LTL and BF (Table 4.1). The difference observed in some of the muscles could be due to the female animals being under metabolic stress due to lactation; five out of the eight animals were in lactation at the time of slaughter. In roe deer there was also no difference found between the pH_u of the LTL muscle of does and stags hunted in Poland (Daszkiewicz *et al*., 2012). Similarly, sex had no effect on the pH_u of the LTL muscle of kudu and impala harvested in Limpopo, South Africa (Hoffman *et al*., 2009). There were also no differences (p = 0.15) observed between the pH_u of male and female fallow deer (Cawthorn *et al*., 2018). Night cropped impala from central Zimbabwe however showed a significant difference in the final pH of rams and ewes; the rams had a higher final pH in comparison to the ewes. This is ascribed to the fact that male impala showed a more active response to the disturbance caused by the culling method as well as the rams were rutting at the time of culling. The age of the impala were however unknown, making accurate comparison difficult (Hoffman, 2000). Engels, (2019) also observed the same trend as Hoffman, (2000) with male impala having a higher pH_u than female impala.

The effect of age and of sex on the water holding capacity of the six impala muscles were determined by measuring the cooking and drip losses. A degree of moisture loss in meat is unavoidable due to the pH of the meat declining to its iso-electric point during the process of post-mortem glycolysis. At the iso-electric point of approximately 5.2, the water binding capacity is at its lowest and thus a small amount of water loss is expected (Lawrie & Ledward, 2006). An accumulation of drip in packaging is however discriminated against by consumers and it should thus be aimed for to decrease the amount of moisture loss of meat products (Troy & Kerry, 2010). Age had no effect on the water holding capacity of the muscles analysed (Table 4.2). Similarly Hoffman *et al.,* (2009) found no difference between the drip loss as well as cooking loss of adult and sub adult Impala. Volpelli *et al*., (2003) also observed no difference between 18-month-old and 30-month-old male fallow deer drip loss and cooking loss percentages for the LTL and SM muscle.

Hoffman *et al.*, (2009) observed no difference in the cooking loss and drip loss percentages of male and female impala LTL muscles. Male and female wild fallow deer also showed no significant difference in drip or cooking loss for the same muscles as analysed in the present study (Cawthorn *et a*l., 2018). In roe deer, no difference was observed for the cooking loss percentage between the male and female LTL muscles. There was however a difference observed in the drip loss percentage with female deer having a higher drip loss than the male deer for the LTL muscle (Daszkiewicz *et al*., 2012) which agrees with the differences found for BF in our study. 18-month-old female impala harvested in the same area as the present study, recorded higher cooking loss for the LTL, BF, SM, IS and SS muscles as well as higher drip loss for the LTL, BF, SM and ST in comparison to the males (Engels, 2019). This was ascribed to a higher pH observed in the male animals resulting in a decreased drip and cooking loss (Engels, 2019).

Shear force is a physical measurement used to quantify the tenderness of meat where low values indicate more tender meat. The following intrinsic factors all have an influence on the shear force and thus tenderness of meat: the amount of connective tissue, the degree of collagen cross linkages, the pH_u, sarcomere length, degree of proteolytic breakdown post-mortem as well as the amount of marbling present (Lawrie & Ledward, 2006; Purchas, 2014). Tenderness was not affected by age for any of the muscles analysed. Likewise, there were no difference observed between the shear force of the LTL muscle of adult and sub-adult impala (Hoffman *et al*., 2009) or springbok (Hoffman, Kroucamp, & Manley, 2007). In contrast to the present findings 30-month- old male fallow deer had a higher shear force for the LTL muscle and thus tougher meat in comparison to the 18-month-old deer (Volpelli *et al.,* 2003). Meat with a shear force below 42.9 N is considered tender (Destefanis *et al.,* 2008). All the muscles analysed for all three age groups fall within the tender classification.

Sex had no effect on the tenderness of majority of the muscles analysed (Table 4.4), nor sex also had no effect on the tenderness of springbok (Hoffman *et al*., 2007) or fallow deer (Cawthorn *et al*., 2018) rams and ewes . In contrast to the current finding, Engels, (2019) found that female impala had a higher shear force than male impala; these were however 18-month-old rams and older ewes (estimated to be between 24 and 36 months old) compared to the present study, which makes comparison between the two studies difficult. However, the BF and ST muscle in this study were also tougher for ewes than for rams. It is suggested that a larger age variation in both impala rams and ewes should be evaluated in future studies to see whether the phenomenon in traditionally farmed livestock of older animals having more tough meat holds.

Consumers rely on meat colour when making purchasing decisions. A bright cherry red colour is associated with freshness and any deviations from that is an indications of potential spoilage (Cornforth & Jayasingh, 2004; Neethling *et al*., 2017). Assessing any factors that might have an influence on meat colour is thus of utmost importance to ensure consumer acceptability. Game meat that fall within a normal pH range is described as having L* > 33, a* > 13, b* ~ 10, C* > 17 and h^{ab} > 36 (Shange, Gouws, & Hoffman, 2019). The L* values for majority of the muscles analysed were below 33 and majority of the b* values were approximately 10 in our study. The a* values were, however, slightly lower than the study of Shange, Gouws, & Hoffman, (2019), Cawthorn *et al*., (2018) and Volpelli *et al*., (2003). Age did not significantly affect the colour measurement of majority of the muscles analysed (Table 4.5). Likewise, there was also no differences observed between lightness, a* (red-green spectrum) and the b* (blue-yellow spectrum) of 18- and 30-month-old male fallow deer LTL and SM muscles (Volpelli *et al*., 2003). In springbok a significant difference in L*, a* b*, h_{ab} and C* were however found between adult and sub-adult animals; the sub-adult animals had a higher L* and thus lighter meat than the adult group. This could, however, be ascribed to the fact that the sub-adult group had a higher final pH. The high pH can possibly outweigh the effect of age and thus make accurate comparison difficult (Hoffman *et a*l., 2007). For impala and kudu harvested in the same area as the present study, age showed no effect on the colour measurements of adult and sub-adult animals (Hoffman *et al*., 2009).

The ewes in the present study had a lower L* value indicating darker meat than the rams. This could possibly be due to ewes having a higher pH_u (Table 4.1) in comparison to the rams for the SM, ST, IS and SS muscles. This results in less water loss and the fibres in the muscle becoming tightly packed together and absorbing more light, thus appearing darker (Lawrie & Ledward, 2006). In contradiction to the current findings, no difference was observed for any colour measurements of the LTL muscle of roe deer bucks and does (Daszkiewicz *et al*., 2012). Sex also did not have any influence on the colour measurements of impala and kudu in the study of Hoffman *et al*., (2009) as well as between roe deer does and stags hunted in Poland (Daszkiewicz *et al*., 2012). No difference was observed between the L* value (p = 0.1210) of male and female fallow deer (Cawthorn *et al*., 2018). In contrast to our findings, Cawthorn *et al*. (2018), recorded higher a* values for female fallow deer in comparison male deer. The same trend was observed between springbok rams and ewes where no difference was observed between the L* values, but the ewes showed higher a* values (Hoffman *et al*., 2007).

The total myoglobin concentration was largely unaffected by age and sex (Table 4.6). The LTL muscle did, however, show a significantly higher concentration in the 42-month-old rams in comparison to its younger counterparts (p = 0.01). In contrast to this, age had no significant effect on the myoglobin content of the LTL muscle of adult and sub-adult impala harvested in the same region (Hoffman *et al*., 2009). In contrast to the current findings, age had a significant effect on the total myoglobin concentration of Hanwoo cows ranging from 1.9 to 11.5 years old (Cho *et al*., 2015).

A significant difference in myoglobin concentration was also noted between 12- and 14-month-old Tucanda bulls finished in intensive or semi-intensive systems (Humada, Sañudo, & Serrano, 2014). Lambs from New Zealand, ranging and grouped in ages from 3 to 4 months and 11 to 12, showed a significant difference in myoglobin concentration (p <0.001) between the two age groups (Kim *et al.,* 2012). The lack of differences observed in the current study could be ascribed to the animals being too young, and further studies are thus needed that include older animals.

Female impala had a significantly higher myoglobin content (10.4 ± 1.98 mg/g) for the LTL muscle in comparison to the rams (8.2 ± 0.56 mg/g). The ewes also had a significantly higher myoglobin content for the SM muscle in comparison to the rams. The other muscles were, however, unaffected by sex. These results are in contrast to other findings. It is generally assumed that the meat from male animals is darker than that of females due to increased levels of myoglobin linked to male animals having a higher level of physical activity (Neethling *et al.*, 2017; Seideman *et al.*, 1982).

4.5 CONCLUSION

An increase in age did not have any detrimental effect on the cooking loss, drip loss, tenderness as well as colour of any of the muscles analysed, under these ante- and post-mortem conditions. It is thus possible to still maintain a high level of quality when impala rams of up to 42-months old are included in game meat production.

Sex had a minor effect on the meat quality of the muscles analysed with differences only observed for some of the muscles. These slight differences can be ascribed to the difference in pH between rams and ewes that could possibly overshadow the effect of sex, making accurate conclusions regarding the effect of sex impossible. Further research is however required that includes a wider range of ages to determine the effect of age and sex over a wider spectrum. Regardless of age and sex, impala meat would appear to have inherently high meat quality characteristics, therefore allowing a larger focus on increasing yield without adversely affecting meat quality.

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CHAPTER 5

PROXIMATE COMPOSITION OF IMPALA MEAT AS INFLUENCED BY AGE AND SEX

ABSTRACT

A total of 24 impala rams and eight ewes were harvested on a game ranch in the Limpopo province, South Africa. The 24 rams consisted of three age groups (18 months, 30 months and 42 months), each of which comprised of eight animals. All eight ewes were 30 months of age. The effect of animal age and sex on the proximate composition of six different muscles (*infraspinatus*, *supraspinatus*, *longissimus thoracis et lumborum*, *biceps femoris*, *semimembranosus* and *semitendinosus*) were analysed. No significant differences were found between the age groups for the majority of the muscles analysed for the moisture (75.0 ± 0.39 - 76.7 ± 0.90 g/100 g), protein (20.8 ± 1.03 - 22.6 ± 0.41 g/100 g), intramuscular fat (1.6 ± 0.31 – 2.4 ± 1.30 g/100 g), ash (1.2 ± 0.07 - 1.6 ± 1.08 g/100 g) or myoglobin content (8.2 ± 1.17 - 11.6 ± 2.17 mg/g). Sex also had no significant effect on the proximate composition nor myoglobin content for the majority of the muscles analysed. Producers and marketers of impala meat should, however, be cautious of completely omitting the effect of age and sex as this is an area that warrants further research.

Keywords: age, impala, proximate composition, sex

5.1 INTRODUCTION

Meat forms an essential part of the human diet, being rich in protein and essential vitamins and minerals. The nutrient density, as well as high protein bioavailability, makes meat an ideal addition to diets containing other cereals and vegetables. In contrast to plant based protein sources, meat also contains all the essential amino acids without containing any limiting amino acids (Bender, 1992; Williams, 2007).

Modern consumers have become more health-conscious and, apart from the price of a product, factors such as environmental sustainability, nutritional value and convenience have become increasingly important in dictating food preferences (Hoffman & Wiklund, 2006). In the past the consumption of red meat from traditional livestock species was linked to cancer and heart disease due to high levels of saturated fat (Radder & le Roux, 2005). It has however, come to light that there is minimal evidence that suggests that a reduction in red meat will prevent cardiovascular diseases as well as cancer (Zeraatkar *et al*., 2019). Consumers perceive that the consumption of game meat has certain health benefits (Wassenaar, Kempen, & van Eeden, 2019). Game meat thus has the potential to serve as a red meat alternative due to its low levels of fat and high protein content (Hoffman & Cawthorn, 2013). Despite this, South Africans are ill-informed regarding the nutritional quality of game meat. Consumers tend to view game meat as of a poor quality and prefer traditional livestock species as their primary source of protein despite associated health risks (Radder & le Roux, 2005).

To market meat efficiently, the nutritional value of the product should be identified. This is partially achieved by performing a proximate analysis, which determines the moisture, protein, intramuscular fat (IMF) and ash content of meat (measured in g/100g or as a %) and accounts for close to 100% of the total weight of any meat sample. The weight of the remaining fraction, consisting of vitamins, glycogen and nucleic acid, is negligibly small and is thus not included in a typical proximate analysis describing the macro nutritional profile of meat (Ang, Young, & Wilson, 1984). Determining and displaying the major chemical components of a product will allow consumers to make informed food choices.

Although the major chemical components of meat do not vary substantially in their proportions, the proportion of IMF tends to vary between breeds, ages, sex, nutrition and the different muscles of an individual animal (Hocquette *et al.*, 2010). Game meat is known for its low amounts of IMF and high protein levels, which makes it an ideal protein source for health-conscious consumers (Hoffman & Cawthorn, 2013). Game meat is also viewed as an organic and free-range product, which, if managed correctly, is an environmentally sustainable product (Hoffman & Wiklund, 2006).

Impala of different ages and sexes have shown to have a high meat yield (Chapter 3) and an inherently high meat quality (Chapter 4). In addition, impala have high reproductive rates and are widely distributed across South Africa and one of the most numerously hunted species (Brooks, 1978; Furstenburg, 2016). With the growth in the game ranching industry in South Africa, impala is one of the first species introduced into any ranch and due to their high fecundity, one of the first species that reproduces in sufficient number to be culled for meat on a regular sustainable basis (Fairall, 1983). To utilise impala as a meat-producing species, the chemical composition as influenced by age and sex is an important factor that needs to be considered to ensure consumer satisfaction. Previous research has focused on the chemical composition of the impala *longissimus thoracis et lumborum* (LTL) muscle (Hoffman *et al.*, 2009; Hoffman, 2000; Van Zyl & Ferreira, 2004) but no research has yet been done on the effect of animal age and sex on the chemical composition of different impala muscles. The aim of this study was thus to determine the influence of animal age and sex on the chemical composition of six different impala muscles namely, the *infraspinatus* (IS), *supraspinatus* (SS), *longissimus thoracis et lumborum* (LTL), *biceps femoris* (BF), *semimembranosus* (SM) and *semitendinosus* (ST).

5.2 MATERIALS AND METHODS

5.2.1 Animals and study location

Thirty-two impala were sourced during an annual culling operation on Romaco Ranch (S24’’ 26’ 43.73” E28” 31’ 25.86”) situated in the Limpopo province, South Africa. The animals were selected and grouped according to age and sex. The rams were divided into three age groups with eight animals per group. The groups consisted of 18-months, 30-months and 42-months-old animals. The eight ewes were all 30 months of age. Ethical clearance (ACU-2018-6598) was granted by the Stellenbosch University Animal Care and Use Committee prior to the initiation of field work.

See Materials and Methods of Chapter 3.2.1 for further details.

5.2.2 Culling and dressing

All the animals were culled according to their age group and sex. Culling took place during the day from a helicopter. Animals were exsanguinated in the field and transported to the registered abattoir (certificate number 2/4G) on the farm for further processing. When the animals arrived at the abattoir, evisceration took place according to the procedure described by Van Schalkwyk and Hoffman (2016). After dressing, the carcasses were kept chilled at 4˚C for 24 hours in order to undergo rigor mortis.

See Materials and Methods of Chapter 3.2.2 for further details.

5.2.3 Sample preparation

After allowing ~24h of cooling, the following muscles were removed from the right side of the carcass: the *infraspinatus* (IS), *supraspinatus* (SS), *longissimus thoracis et lumborum* (LTL), *biceps femoris* (BF), *semimembranosus* (SM) and *semitendinosus* (ST). All the muscles were vacuum packed and frozen at −20˚C until further analysis.

5.2.4 Chemical analysis

5.2.4.1 Sample preparation for chemical analysis

Whole frozen muscles were removed from the −20˚C freezer and allowed to thaw overnight at 4˚C. All visible epimysium was removed, and approximately 200 g of the samples were cut into smaller pieces to ensure efficient homogenisation until a paste-like consistency was achieved. The sample was then divided into bags and vacuum-sealed and frozen again at −20˚C to prevent any moisture loss. In preparation for the respective chemical analyses, the samples were thawed overnight at 4˚C.

5.2.4.2 Proximate analysis

Proximate analysis was carried out on each sample. The moisture content (g/100g) was determined by drying a 2.5 g sample of each homogenised muscle in a 100˚C oven for 48 hours in accordance with the AOAC Official Method 934.01 (AOAC International, 2002c). To determine the ash content (g/100g), the moisture-free sample was placed in a 500˚C furnace for six hours according to AOAC Official Method 942.05 (AOAC International, 2002a).

IMF content (g/100g) was determined using a rapid solvent extraction method (Lee, Trevino, & Chaiyawat, 1996). The solvent used for this analysis was a chloroform/methanol mixture with a 1:2 ratio (v/v); the ratio recommended for meat samples with a low lipid content.

The crude protein content (g/100g) was determined by drying the remaining filtrate from the IMF analysis at 60˚C. The remains were then ground to a fine powder and 1g thereof was enclosed in a LECO™ tinfoil sheet to be analysed in a LECO Nitrogen/Protein Determinator (FP528 – LECO Corporation) in accordance with the Dumas combustion method as described by the AOAC Official Method 992.15 (AOAC International, 2002b). A 0.15 g sample of EDTA was combusted after every batch of 12 samples for calibration (LECO Corporation, USA). Results (Nitrogen) were converted to crude protein content (g/100g) by multiplying with a factor of 6.25.

5.2.5 Statistical analysis

A completely randomised design was used for both the age and sex data as independent main effects. Chemical composition data were analysed with Statistica version 13.4 (2018). A variance estimation and precision model was used. A mixed model repeated-measures procedure was used to perform an analysis of variance (ANOVA). A Shapiro-Wilk test was performed on the standardised residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). If a significant deviation from normality was observed, such as when the standardised residual for an observation deviated with more than three standard deviations from the model value, outliers were evaluated and where applicable, removed. To compare the means (for the age data), a Fisher's t-least significant difference was calculated at a significance level of 5% (Ott, 1998).

5.3 RESULTS

5.3.1 Proximate composition

The proximate composition (moisture, protein, IMF and ash) was determined on the *infraspinatus* (IS), *supraspinatus* (SS), *longissimus thoracis et lumborum* (LTL), *biceps femoris* (BF), *semimembranosus* (SM) and *semitendinosus* (ST) for 42-, 30-, and 18-month-old rams as well as between 30-month-old rams and ewes.

Age had a significant effect on the BF (p = 0.04) and SM (p <0.01) muscle moisture content (Table 5.1). For both muscles, the 30-month-old animals had a higher moisture content than both the 18- and 42-month-old animals. Sex had a significant influence on the moisture content of the SM muscle (p = 0.02) with the rams having the higher moisture content. Age also had a significant effect on the protein content of the BF (p=0.03) and SM (p <0.01) muscles; for both muscles the 30-month-old animals had a lower protein content in comparison to the other age categories. Sex also had a significant effect (p <0.01) on the protein content of both the SM and BF muscles; for both muscles, the rams had the lower protein content. Neither age nor sex had any effect on the IMF and ash content for any of the muscles analysed. The muscles all had low IMF contents (1.6-2.4 g/100g muscle), whilst the ash varied between 1.2 and 1.3 g/100 g muscle.

Table 5.2 illustrates the significant differences in proximate composition for the six impala muscles per age and sex group. There was a difference (p <0.01) between the moisture content of the 18-month-old impala muscles. The ST, IS and SS muscles had a higher moisture content than LTL, BF and SM muscles.

Table 5.1 Proximate composition (g/100g) of impala meat as influenced by age and sex. Values indicated as least square means (±standard deviation).

		Age (Months)				Age	*Sex
		42; M	*30; M	18; M	*30; F	*p*-value	*p*-value
Moisture (g/100g)	LTL	75.5 ± 1.08	75.6 ± 0.54	75.3 ± 0.53	75.1 ± 0.96	0.58	0.15
	BF	**75.3^{b} ± 0.77**	**76.2^{a} ± 0.77**	**75.4^{b} ± 0.68**	75.5 ± 0.55	**0.04**	0.07
	SM	**75.0^{b} ± 0.39**	**76.1^{a} ± 0.90**	**75.5^{b} ± 0.38**	**75.2 ± 0.46**	**<0.01**	**0.02**
	ST	75.5 ± 2.71	75.7 ± 0.87	76.5 ± 0.73	75.9 ± 1.08	0.50	0.70
	IS	75.7 ± 0.82	76.4 ± 0.76	76.4 ± 0.80	76.5 ± 1.34	0.22	0.89
	SS	75.9 ± 1.06	76.4 ± 1.08	76.3 ± 1.39	76.7 ± 0.90	0.76	0.52
Protein (g/100g)	LTL	21.7 ± 1.22	21.8 ± 0.74	22.6 ± 0.74	22.5 ± 1.13	0.12	0.15
	BF	**22.2^{a} ± 0.78**	**21.3^{b} ± 0.53**	**22.2^{a} ± 0.81**	**22.3 ± 0.73**	**0.03**	**<0.01**
	SM	**22.5^{a} ± 0.65**	**20.9^{b} ± 1.41**	**22.6^{a} ± 0.41**	**22.5 ± 0.60**	**<0.01**	**<0.01**
	ST	22.0 ± 2.60	21.9 ± 0.83	21.5 ± 0.75	22.1 ± 0.89	0.82	0.61
	IS	21.9 ± 0.92	21.5 ± 0.94	21.6 ± 0.97	21.4 ± 1.13	0.70	0.86
	SS	21.4 ± 1.30	20.9 ± 1.19	20.9 ± 0.77	20.8 ± 1.03	0.61	0.80
IMF (g/100g)	LTL	1.7 ± 0.37	2.0 ± 0.56	1.7 ± 0.16	1.8 ± 0.61	0.31	0.48
	BF	2.0 ± 0.34	2.3 ± 0.75	1.8 ± 0.34	1.8 ± 0.64	0.14	0.15
	SM	2.0 ± 0.43	2.0 ± 0.62	1.7 ± 0.22	1.7 ± 0.47	0.37	0.20
	ST	1.8 ± 0.25	1.8 ± 0.34	1.6 ± 0.31	1.8 ± 0.58	0.50	0.93
	IS	2.0 ± 0.32	2.2 ± 0.55	1.9 ± 0.33	2.1 ± 0.63	0.23	0.76
	SS	2.2 ± 0.52	1.9 ± 0.49	2.4 ± 1.30	2.2 ± 0.49	0.54	0.33
Ash (g/100g)	LTL	1.3 ± 0.15	1.3 ± 0.11	1.2 ± 0.13	1.3 ± 0.13	0.67	0.71
	BF	1.3 ± 0.39	1.2 ± 0.05	1.2 ± 0.10	1.3 ± 0.11	0.55	0.07
	SM	1.3 ± 0.11	1.2 ± 0.08	1.3 ± 0.16	1.2 ± 0.11	0.47	0.62
	ST	1.3 ± 0.28	1.2 ± 0.12	1.3 ± 0.04	1.3 ± 0.09	0.60	0.27
	IS	1.2 ± 0.47	1.2 ± 0.07	1.2 ± 0.10	1.2 ± 0.12	0.86	0.79
	SS	1.2 ± 0.14	1.6 ± 1.08	1.3 ± 0.14	1.2 ± 0.12	0.52	0.37

*Sex comparison between 30-month-old male and 30-month-old female animals

[a,b,c] Means with different superscripts in the same row differ significantly from each other ($p \leq 0.05$).

A difference (p <0.01) was observed between the moisture content of the different muscles of the 30-month-old female animals. The SS had the highest moisture content and differed from the LTL, BF, SM and ST. The protein content of the 18-month-old rams differed significantly (p <0.01) between the different muscles. The LTL and SM had the highest protein content and differed from the ST, IS and SS. The protein content also differed (p <0.01) between the different muscles of the 30-month-old female animals. The LTL, SM and BF had the highest protein content and differed from the IS and SS. The IMF content differed (p = 0.05) between the muscles of the 42-month-old animals; the SS had the highest IMF content and differed from the LTL and ST. The IMF content also differed (p = 0.04) between the muscles of the 30-month-old female animals; the SS had the highest IMF content and differed from the LTL, BF and SM muscles.

Table 5.2 Influence of muscle on the proximate composition of impala. Values indicated as least square means (±standard deviation).

	Age/Sex	LTL	BF	SM	ST	IS	SS	*p*-value
Moisture (g/100g)	18 M	**75.5^{b} ± 1.08**	**75.3^{b} ± 0.77**	**75.0^{b} ± 0.39**	**75.5^{a} ± 2.71**	**75.7^{a} ± 0.82**	**75.9 ^{a}± 1.06**	**<0.01**
	30 M	75.5 ± 1.08	75.3 ± 0.77	75.0 ± 0.39	75.5 ± 2.71	75.7 ± 0.82	75.9 ± 1.06	0.31
	42 M	75.5 ± 1.08	75.3 ± 0.77	75.0 ± 0.39	75.5 ± 2.71	75.7 ± 0.82	75.9 ± 1.06	0.73
	30 F	**75.5^{d} ± 1.08**	**75.3^{cd} ± 0.77**	**75.0^{cd} ± 0.39**	**75.5^{bc} ± 2.71**	**75.7^{ab} ± 0.82**	**75.9^{a} ± 1.06**	**<0.01**
Protein (g/100g)	18 M	**21.7^{a} ± 1.22**	**22.2^{ab} ± 0.78**	**22.5^{a} ± 0.65**	**22.0^{bc} ± 2.60**	**21.9^{bc} ± 0.92**	**21.4^{c} ± 1.30**	**<0.01**
	30 M	21.7 ± 1.22	22.2 ± 0.78	22.5 ± 0.65	22.0 ± 2.60	21.9 ± 0.92	21.4 ± 1.30	0.22
	42 M	21.7 ± 1.22	22.2^{a}± 0.78	22.5 ± 0.65	22.0 ± 2.60	21.9 ± 0.92	21.4 ± 1.30	0.66
	30 F	**21.7^{a} ± 1.22**	**22.2^{a} ± 0.78**	**22.5^{a}± 0.65**	**22.0^{ab} ± 2.60**	**21.9^{bc} ± 0.92**	**21.4^{c} ± 1.30**	**<0.01**
IMF (g/100g)	18 M	1.7 ± 0.37	2.0 ± 0.34	2.0 ± 0.43	1.8 ± 0.25	2.0 ± 0.32	2.2 ± 0.52	0.07
	30 M	1.7 ± 0.37	2.0 ± 0.34	2.0 ± 0.43	1.8 ± 0.25	2.0 ± 0.32	2.2 ± 0.52	0.23
	42 M	**1.7^{b} ± 0.37**	**2.0^{ab} ± 0.34**	**2.0^{ab} ± 0.43**	**1.8^{b} ± 0.25**	**2.0^{ab} ± 0.32**	**2.2^{a} ± 0.52**	**0.05**
	30 F	**1.7^{c} ± 0.37**	**2.0^{bc} ± 0.34**	**2.0^{c} ± 0.43**	**1.8^{abc} ± 0.25**	**2.0^{ab} ± 0.32**	**2.2^{a} ± 0.52**	**0.04**
Ash (g/100g)	18 M	1.3 ± 0.15	1.3 ± 0.39	1.3 ± 0.11	1.3 ± 0.28	1.2 ± 0.47	1.2 ± 0.14	0.70
	30 M	1.3 ± 0.15	1.3 ± 0.39	1.3 ± 0.11	1.3 ± 0.28	1.2 ± 0.47	1.2 ± 0.14	0.40
	42 M	1.3 ± 0.15	1.3 ± 0.39	1.3 ± 0.11	1.3 ± 0.28	1.2 ± 0.47	1.2 ± 0.14	0.82
	30 F	1.3 ± 0.15	1.3 ± 0.39	1.3 ± 0.11	1.3 ± 0.28	1.2 ± 0.47	1.2 ± 0.14	0.14

^{a,b,c,d} Means with different superscripts in the same row differ significantly from each other ($p \leq 0.05$).

5.4 DISCUSSION

This study aimed to quantify the effect of animal age and sex on the proximate composition of impala meat; the ages of both sexes were typically that which farmers would cull/hunt from their breeding herds. This information will be of value for the producers who are looking at marketing impala meat into the formal market where the nutritional composition of the meat is an important factor determining consumer choice.

Water serves as the major component in meat ranging from 75% to 80% of the cell's weight post mortem (Keeton & Eddy, 2004). Game species tend to have a higher moisture content in their muscle in comparison to other livestock species due to having a higher proportion of protein to intramuscular fat. The moisture content is typically inversely correlated to the fat content of tissue, particularly when the IMF levels are high (Aidoo & Haworth, 1995; Hoffman, Kroucamp, & Manley, 2007). The moisture content was largely unaffected by age and although some differences did arise the magnitude there of was very small and potentially have no commercial or nutritional significance (Table 5.1). Age also did not affect the moisture content of adult and sub-adult impala harvested in the same area as the current study (Hoffman *et al.*, 2009); in fact the impala had a similar moisture content of 74.7 g/100g for sub-adult and 75 g/100g for adult impala LTL muscles. In springbok meat, a difference was observed between the moisture content of adults and lambs, but not between adults and sub-adults (Hoffman, Kroucamp, & Manley, 2007). The LTL of male fallow deer also showed no significant difference between 18- and 30-months-old deer (Volpelli *et a*l., 2003). The moisture content of the SM muscle was significantly (p = 0.04) higher for the 30-month-old rams in comparison to the other age groups. This is in contrast to the moisture content observed for the SM muscle of male fallow deer that had no significant difference between the age groups (Volpelli *et al.*, 2003). The significant difference observed for the SM muscle is however negligible because the slight difference will potentially have no economic or nutritional value.

Apart from the SM muscle, sex had no influence on the moisture content. Similarly, Hoffman *et al*., (2009) found no difference between the moisture content of the LTL muscle of impala ewes and rams harvested in the same area to that of the present investigation. In contrast, impala harvested in the Bredasdorp area of the Western Cape showed a significant difference in moisture content, with males having a higher percentage moisture than females (Van Zyl & Ferreira, 2004); the accuracy of these results is, however, questionable, as a sample size of two males and six females was used. Springbok rams had a significantly higher moisture content in comparison to the ewes. This could be attributed to the female animals' high fat content which, due to the inverse correlation between fat content and moisture content frequently reported, results in a subsequent lower moisture content (Hoffman, Kroucamp, & Manley, 2007). Sex also had no significant effect on the moisture content of blesbok harvested near Witsand in the Western Cape, South Africa (Neethling, Hoffman, & Britz, 2014).

The protein content of game species varies between 20 and 24 g/100g and is generally higher than that of traditional livestock species (Hoffman & Cawthorn, 2013). In game species, a stronger negative correlation exists between the moisture content and protein content due to the low levels of IMF present (Neethling, Hoffman, & Britz, 2014). The lower protein content of the SM and BF muscle (Table 5.1) can be attributed to the higher moisture content observed. Despite these differences observed the effect there of will be negligible due to potentially having no economic or nutritional value. Impala harvested in the same area showed a similar protein content of 22.6 g/100g for adult and 23.4 g/100g for sub-adult rams (Hoffman *et al*., 2009). In male fallow deer, there was also no significant difference between the protein content of 30- and 18-month-old animals (Volpelli *et al*., 2003). Apart from the BF and SM muscle, sex had no significant effect on the protein content. Impala harvested in Zimbabwe also showed no significant difference in protein content between rams and ewes (Hoffman, 2000). In contrast to other findings, a significant difference in protein content in male and female roe deer was reported; the females having a higher protein content (Daszkiewicz *et al*., 2012). This was ascribed to the males' higher moisture content, which subsequently, results in a lower protein content.

The IMF content of game species varies between 2.0 and 2.5 g/100g and is generally lower than other livestock species (Hoffman & Cawthorn, 2013). Age and sex had no significant effect on the IMF content of any of the muscles analysed with the content varying between 1.6 and 2.4 g/100g muscle (Table 5.1). Age also did not affect the fat content of adult and sub-adult impala harvested in the same area (Hoffman *et al*., 2009). In contrast to this, 30-month-old male fallow deer showed a significantly higher IMF content in comparison to 18-month-old fallow deer (Volpelli *et al*., 2003).

According to Ledger, Sachs and Smith (1967), female ungulates tend to have a slightly higher IMF content in comparison to males. However, the ewes in this study were under metabolic stress due to lactation (Chapter 3), which could have led to a lower than usual IMF content. The rams on the other hand were preparing for the rut and were depositing fat in their necks that serve as an energy reserve during the rut. The rams had a body condition score of between 2 – 3 ± 0.5 whilst the ewes had a lower body condition score of between 1 – 2 ± 0.5 (Chapter 3). This could have led to the rams having the same IMF content as the ewes. The IMF content, being unaffected by sex in the present study, contradicts previous research. For impala harvested in the same area (Hoffman *et al*., 2009) as well as impala harvested in Zimbabwe (Hoffman *et al*., 2000), the female animals showed a significantly higher IMF content. A similar trend was also noted between male and female roe deer harvested in Poland (Daszkiewicz *et al.,* 2012). Sex also had a significant effect on the IMF content of springbok, blesbok and impala harvested in the Karoo, Free State and Western Cape. For all three species the female animals had a higher IMF content in comparison to the males (Van Zyl & Ferreira, 2004).

The ash content gives an estimation of the total mineral content present in meat (Keeton & Eddy, 2004). The ash content of game meat varies between 1.0 and 2.4 g/100g (Hoffman &

Cawthorn, 2013). The ash content of the muscles analysed was also unaffected by both age and sex (Table 5.1). Similarly, age had no effect on the ash content of impala harvested in the same area as the present study (Hoffman *et al.*, 2009). Sex also had no effect on the ash content of springbok, blesbok and impala harvested in the Karoo, Free State and Western Cape (Van Zyl & Ferreira, 2004). The ash content of roe deer was also unaffected by sex (Daszkiewicz *et al*, 2012). It would seem as if the ash (mineral) content o game meat and venison is very similar across ages and sexes as noted by Hoffman & Cawthorn (2013).

The anatomical location, species, breed, age, sex, plane of nutrition and level of exertion are all factors that can influence the composition of skeletal muscles (Lawrie & Ledward, 2006). The anatomical location is the main factor that influences the chemical composition of muscles due to differences in function, activity and growth. These differences between muscles results in varying muscle fibre types, connective tissue and IMF levels (Lawrie & Ledward, 2006; Taylor, 2004). Differences in the proximate composition of muscles, as seen in Table 5.2, was thus expected. The SS, IS and ST muscles of the 18-month-old rams had a higher moisture content than the LTL, BF and SM muscles. This is in accordance to Fitzhenry, (2016) who also noted that the SS, IS and ST had a higher moisture content in comparison to the other muscles of wild fallow deer. These differences could be due to the inverse correlation between moisture and protein content (Neethling, Hoffman, & Britz, 2014) as mentioned earlier. The LTL and SM muscles had a higher (p <0.01) protein content than the ST, IS and SS muscles of 18-month-old rams. This same trend was also observed for the 30-month-old female animals as well as by Fitzhenry, (2016).

5.5 CONCLUSION

The chemical composition of impala meat was largely unaffected by animal age or sex. All the chemical components analysed did however, fall within the normal range for game meat. Male impala ranging in ages from 18 months to 42 months can thus be used for meat production without causing variation in the chemical composition of the meat between the ages. It is advised that future studies include a wider age spectrum for both sexes to asses if the current findings are applicable over a wider age range. Future studies should also evaluate the differences between seasons, as impala are seasonal breeders and season could affect the chemical composition of the meat. The results obtained can assist producers in accurate labelling and the education of consumers regarding the positive attributes of impala meat. When marketing impala meat, the nutritional differences between muscles due to anatomical location should be taken into account. Producers and marketers should however, be cautious of completely omitting the effect of age and sex as this is an area that warrants further research.

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CHAPTER 6
GENERAL RECOMMENDATIONS AND CONCLUSION

The aim of this study was to quantify the effect of animal age and sex on the yield, physical quality and chemical composition of impala (*Aepyceros melampus*) meat. The baseline data generated in this study could aid the game meat industry in effective marketing, consumer education and bettering farming practises. The production of high-quality impala meat could contribute to food security, economic development and environmental sustainability in South Africa. The majority of impala that are culled for meat production are surplus animals culled as a means of population management in breeding programs.

Animal age significantly affected the dead weight and warm carcass weight of the impala rams. The 42-month-old animals had the highest yield in term of carcass weight, muscle as well as organ yield. The dressing percentage was, however, unaffected by age. If the area limitations are taken into account, the 18-month-old animals showed the highest yield. This is due to stocking density limitations linked to the sigmoidal growth curve of impala as well as the influence of mortality being more severe on older animals. It is recommended that a proportional cutting block-test be performed on impala of different ages to quantify the meat to bone ratio of the different age groups. It is also advised that a wider range of ages be investigated to give a more accurate representation of the effect of age on impala meat yield. A serial slaughter experiment, to determine an accurate growth curve for impala from different locations within Southern Africa, is also an area that warrants further research. This will make it possible to accurately determine the ideal age at which to slaughter impala in terms of both yield and meat quality. Such an experiment should take the reproductive cycle of impala into account as they are seasonal breeders. The value of the meat produced per surface area would also be a valuable point of consideration.

The meat quality was largely unaffected by both age and sex. This could indicate that impala have an inherently high meat quality and thus a larger focus can be placed on increasing the meat yield without adversely affecting the quality. A wider age spectrum is needed though for both the age and sex treatments to ensure that the data is robust. The muscle fibre type and collagen content of impala of various ages should also be quantified to determine the influence these factors have on meat quality. This will also give a deeper understanding of the variation observed between muscles.

The chemical composition was also mainly unaffected by both age and sex. All the chemical components analysed were within the normal rage for game meat. It was once again concluded that game meat is high in protein and low in fat, making it the ideal choice for health-conscious consumers. A wider range of ages is, however, needed to see if any variation in the chemical composition will occur over a wider age spectrum. The study should also be repeated over different times of the year, as impala are seasonal breeders; season could especially influence the amount of intramuscular fat present in both male and female impala.

To ensure the overall success and growth of the game meat industry market research is needed both locally and internationally to increase the export as well as local consumption of game meat. Consumer education is also needed on the positive health and environmental attributes of game meat.